TECHNICAL MEMORANDUM **CH2MHILL**

Kinder Morgan Linnton Terminal River Bank Erodability Assessment

PREPARED FOR:	Kinder Morgan Liquids Terminals LLC
PREPARED BY:	Todd Cotten/CH2M HILL
COPIES:	Keith Sheets/CH2M HILL Eric Aronson/CH2M HILL Jeff Gentry/CH2M HILL
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REGISTERED PROFESSIONAL ENGINEER
58496 PE
OREGON
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TODD E. COTTEN
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Introduction

This technical memorandum (TM) presents the bank soil erodability analyses performed for the Kinder Morgan Linnton Terminal (the Site), located at 11400 NW Saint Helens Road in Portland, Oregon (Multnomah County) (see Figure 1). The Site is on the west bank of the Willamette River between approximate river mile (RM) 4.1 and 4.3 within the Portland Harbor.

Purpose and Scope

The purpose of the bank soil erodability analyses is to assess the potential for erosion of bank soils at the Site. For the purposes of this evaluation, the bank soils are defined as soils located on the embankment that extends from the top of slope to the bottom of steep portion of the slope adjacent to the Willamette River. Figure 2 provides an aerial view of the project site including the bank along the Willamette River. The portion of the bank that is generally below water much of the year and sloped at 5 horizontal to 1 vertical (H:V) or flatter is considered to be part of the river sediment or river shore and was not considered in this analyses.

Bank soils determined to be susceptible to erosion will be sampled and tested as part of a subsequent task to determine if constituents of potential concern (COPC) are present and may act as a source of contamination to the Willamette River.

This assessment was preceded by completion of a topographic survey and aerial photographing of the Site. Site topographic mapping showing bank geometry and aerial photographs were used during site visits to evaluate and document existing bank conditions. Observations of river bank conditions and materials present at the surface of the river bank across the Site were documented during the site visits. Measurements of armoring stone (riprap) were made and photographs were taken to add a visual record of existing conditions.

This erodability assessment includes evaluation of bank soil erosion from the following processes:

1. Currents in the Willamette River during flood events
2. Wind generated waves
3. Boat generated waves
4. Surface water runoff and precipitation
5. Mass wasting or landsliding

Approach

The approach for evaluating erosion potential at the site was to first evaluate existing materials on the river bank and make an assessment of current conditions. Samples of bank material was collected in areas that were observed to be void of larger armoring stone and thus could potentially be subject to erosion. Laboratory grain size analyses were completed on these samples and the results evaluated against the critical particle sizes necessary to resist erosion from the erosion processes listed above. This approach follows the Bank Soils Investigation Work Plan submitted to DEQ on September 8, 2010.

Elevations presented in this document are referenced to the North American Vertical Datum of 1988 (NAVD88) unless noted otherwise. Stationing presented herein is shown on Figure 3. The station line is set at the top of the river bank with Station 0+00 being located at the northern limit (down river end) of the Kinder Morgan property. Station 10+52.8 is located at the southern extent (upstream end) of the Site (1,052.8 feet from Station 0+00).

Kinder Morgan Liquids Terminal LLC is a member of the Lower Willamette Group (LWG). Information and data prepared for the LWG as part of a number of assessments, including the 2004 Remedial Investigation/Feasibility Study (RI/FS) Programmatic Work Plan and the 2009 Draft RI/FS are referenced in this document. The 2009 Draft RI/FS is currently under review and is subject to revision in whole or part. However, the portions of the document referenced herein are factual in nature, are not based on interpretation and are therefore not anticipated to be revised.

Site Background

Kinder Morgan's Linnton Terminal, shown on Figures 2 and 3, is approximately 17 acres with approximately 1,050 feet of shoreline. The facility has been used as a storage and distribution terminal for petroleum products (gasoline, diesel, and lubricating oil) dating back to as early as 1918 and it is currently used to store and distribute gasoline and diesel fuel (KMH, 2002).

Based on a review of historical drawings and aerial photographs of the site it appears that site was built up by placing fill material along the eastern portion of the site to develop a relatively flat tank yard. The first fill material was placed at the northeast portion of the site prior to 1925 and additional fill material was placed at the southeast edge of the site between 1939 and 1942.

A dock structure for unloading fuel from ships was constructed offshore in the Willamette River at the site prior to 1926. Facility drawings show that walkways at the north and south ends of the dock were designed in 1991 and most likely constructed in or around 1992. The dock and associated walkways are founded on timber pile and extend from near the northern end of the property for more than 700 feet to the south. Typically the timber pile foundations consists of at least two rows of piles running parallel to the shore, but in some areas up to five rows of piles are present. The timber piling associated with the dock structure act to break up boat and wind generated waves that originate on the river and help to protect about two-thirds of the river bank. The protection is greatest in the areas that include the highest concentration of piling. Pictures of the existing dock structure are shown in Photographs 1 and 2 in Appendix A.

A topographic survey drawing from 1925 and a facility drawing from 1939 both show timber pile and lagging bulkheads were present from the northern end of the site and extending south approximately 680 feet along the bank of the Willamette River. The timber pile were shown to be spaced at 8 foot centers. Two rows of timber pile and lagging bulkheads existed along the river bank from approximate Stations 0+00 to 4+88 and three rows of bulkheads existed between Stations 4+88 and 6+80.

A facility design drawing from 1941 shows that the three rows of bulkheads present from Station 4+88 to 6+80 were to be extended to the southern extent of the property at a spacing of 10 feet on centers. The elevations of the three rows of bulkheads are shown to be approximately 25, 16, and 11 feet for the top, middle, and lower bulkhead rows, respectively. Facility drawings from after 1942 show two to three rows of the timber pile and lagging bulkheads existing along the entire extent of the Willamette River bank.

Existing Site Conditions

Ground surface elevations range from approximately 39 feet at the west side of the site near the Burlington Northern Railroad tracks to approximately 30 feet at the east side of the site at the top of the river bank leading down to the Willamette River. The majority of the river bank below elevation 30 is covered with cobble- to boulder-sized basalt riprap. The slope of the river bank varies across the Site. The slope of the river bank is more uniform south of Station 7+00. North of this station, the river bank generally becomes steeper higher up the slope. The steepest slopes near the top of the river bank north of Station 7+00 generally have slopes between 1.5 horizontal to 1 vertical (H:V). The portions or the river bank near the toe of the slope and just above the transition to the river shore and sediment zone are generally flatter than 3.5H:1V.

The two to three rows of timber pile and lagging bulkheads shown on the historic facility drawings between Station 0+00 and 6+80 are visible in most, but not all areas. Where they are present, they remain in a state of disrepair. The timber pile show signs of significant rot and the timber lagging are no longer present between some of the timber piles. In addition, the bulkheads are not visible between approximate Station 0+00 and 0+80. The bulkheads shown on historic facility drawings south of Station 6+80 are not visible at the site and there is no visual evidence that they are present.

The existing river bank geometry and the materials present at the surface of the riverbank are discussed in the following sections. The discussion is broken out to discuss areas that have similar geometry and bank material characteristics. The discussion of river bank materials and geometry is followed by a discussion of the Willamette River's characteristics and dynamics in the vicinity of the project site.

River Bank Geometry and Materials

Station 0+00 to 0+50

The river bank slope between Stations 0+00 and 0+50 angles westward or slightly away from parallel to the Willamette River. The northern walkway to the Kinder Morgan loading dock is located at approximate Station 0+50 and the piles associate with the walkway provide some protection of the river bank from waves and river currents moving down river.

The upper portion of the river bank surface along this section consists of rubble fill that includes large slabs of concrete mixed with gravel and soil. The concrete chunks are generally between 6 and 12 inches thick and between 1 and 5 feet in planar dimensions. The bank along this area is very steep, with a few areas that are steeper than 1H:1V. Below about elevation 16 feet, bank material consists of an angular to sub-angular basalt riprap ranging in size from about 24 inches to 4 inches diameter. The medium size of riprap in this area is about 12 inches. This material extends below the bottom of the steep portion of the bank that is at approximate elevation 12. Woody debris and logs are present on top of the riprap at the bottom of the bank.

The orientation of the river bank, combined with the presence of woody debris at the bottom of the slope and the fact that the walkway piles protects this area from floating debris suggests that this may be an area where the river eddies during flood events.

While the concrete rubble on the upper bank provides protection against some forms of bank erosion, it appears that the material was not placed in a controlled manner and the soil component of the bank material is very loose. Areas of voids are visible beneath some of the concrete slabs. Based on a visual examination, it appears that the soil component of the fill could be subject to erosion during large flood events. The oversteepend sections of the bank may also be subject to minor slumps that could expose new bank material, although it appears that the additional fill material would be present behind the currently exposed fill and that bank erosion would not be extensive.

There is evidence of minor erosion of the bank in this area from surface water runoff. Surface water appears to collect at the top of the bank and flow around the existing mooring dolphin and over the bank near Station 0+20. The area where signs of surface water erosion was noted in shown in Figure 3.

Pictures of this section of the site are presented in Photograph 3 and 4 Appendix A of this TM.

Station 0+50 to 1+60

The section of river bank between Stations 0+50 and 1+60 is covered by angular to sub-angular basalt riprap from the toe of the bank up to an elevation of 18 feet. The riprap ranges in size from greater than 2 feet diameter to less than 4 inches in diameter with the average size being about 10 inches in most places. The lower portion of the bank is well protected against erosion.

The upper portion of the slope in this area is variable. In some areas relatively large armoring stone (up to 18 inches diameter) protects the upper slope, but in others the largest armoring stones appear to have rolled away from the upper portion of the bank leaving behind a mixture of small cobbles, gravels, and soil. This is the case between approximate Stations 0+80 and 1+40 where the bank between approximate elevation 24 and 30 consist of a mixture of cobbles, gravels, and soil. The slope along this upper steep portion of the bank is approximately 1H:1V. The lower portion of the bank has a slope between 2H:1V and 2.5H:1V.

The upper row of timber pile bulkhead is not visible along most of this section. Four to five timber piles are visible at the ground surface between Station 0+80 and 1+10, but they are flush with the ground surface. It appears that surface water from the terminal facility flows over the portion of the bank between approximate Stations 0+80 and 1+40 during heavy rain events. There are no signs of concentrated flow therefore it's expected that any flow occurs in sheets. Consequently, there is no major erosion from surface water runoff.

A bulk sample of bank material was collected for grain-size analyses along the upper portion of the bank at Station 1+30 as shown in Figure 4A. The sample was labeled as G-4-2010.

Pictures of this section of the site are presented in Photographs 5 through 8 in Appendix A of this TM. Photograph 8 shows the location where sample G-4-2010 was collected.

Station 1+60 to 4+70

The section of river bank between Stations 1+60 and 4+70 is similar to the section between Stations 0+50 and 1+60. The major difference is that the upper bulkhead is present and continuous along this section of the site and that the riprap armoring along the upper portion of the slope has remained in place over most of the bank. There are only small and isolated areas where some of the larger riprap appears to be missing from the upper sections of the bank between elevations 26 and 30 feet.

The upper bulkhead limits the potential for surface water to flow over the bank. There are no signs of erosion from surface water flowing over the bank in this area.

A bulk sample of bank material was collected for grain-size analyses along the upper portion of the bank at Station 4+35 and shown in Figure 4A. The sample was labeled as G-3-2010.

Pictures of this section of the site are presented in Photographs 9 through 11 of Appendix A. Photograph 11 shows the conditions where sample G-3-2010 was collected.

Station 4+70 to 6+80

The section of river bank between Stations 4+70 and 6+80 is characterized by more competent sections of timber pile and lagging bulkhead that sometimes retain upslope bank material and extend above the downslope bank materials. Historically, there have been three rows of bulkheads along this section of the river bank. Today, most sections of the three bulkheads are still visible with the condition of the bulkheads improving from the lower row to the upper row. The lower bulkhead is missing the timber lagging between piles in most locations.

Riprap armoring ranging in size from over 2 feet diameter down to large gravel and cobbles having dimensions of 3 to 4 inches diameter cover the bank between the bulkheads.

Between Stations 4+70 and 4+90 and Stations 6+20 and 6+80 the upper and middle bulkheads extend above the downslope ground surface and retain bank material upslope of the bulkheads. In these areas the ground surface between the upper and lower bulkheads is relatively flat (about 4H:1V). The ground surface between the middle and upper bulkhead is covered with basalt riprap in most locations. In a few isolated areas the ground surface is covered with rounded river rock with occasional angular basalt. A bulk sample of bank material was collected for grain-size analyses in one of these areas where the rounded rock ranged in size from less than 1 to 6 inches in diameter. The average size of the rounded rock at the surface was about 2 inches. Beneath the surface, the material consisted of a mixture of gravel and sand. The sample, labeled as G-2-2010, was collected at Station 6+45 as shown in Figure 4B.

Pictures of this section of the site are presented in Photographs 13 through 17 in Appendix A. Photograph 17 shows the conditions where sample G-2-2010 was collected.

Station 6+80 to 9+70

The section of bank between Station 6+80 and 9+70 is the most heavily armored section of river bank at the Site. The riprap armoring extends from below the river bank toe to the top of the slope near elevation 30 feet and consists of angular basalt. The riprap ranges in size from greater than 4 feet to less than 6 inches diameter with the average size being about 16 inches. The riprap extends well below the toe of the bank in this area.

The bank slope in this area is steepest near the top of the bank at approximately 1.5H:1V. Further down on the bank the slope is flatter than 3H:1V. There are no signs of erosion from surface water runoff or other mechanisms in this area.

Pictures of this section of the site are presented in Photographs 18 through 21 in Appendix A. No samples were collected from this section for grain size analyses.

Station 9+70 to 10+52.8 (South end of Site)

The lower portion of the river bank between approximate elevations 10 and 18 and between Station 9+70 and the south end of the property is covered with basalt riprap having similar characteristics as those described for Station 6+80 and 9+70 (above). The portion of the bank above this elevation consists primarily of sand and gravel with occasional cobbles and boulder-sized riprap pieces.

The bank in this area angles westerly or slightly away from parallel to the river. The only significant vegetation along the entire river bank slope is also located in this area and consists of several small trees and bushes.

There is evidence of minor erosion of the bank in this area from surface water runoff. Surface water appears to collect at the top of the bank and flow down the bank near Station 10+00. The area where signs of surface water erosion were observed is shown in Figure 3.

A bulk sample of bank material was collected for grain-size analyses along the upper portion of the bank near Station 10+05 as shown in Figure 4B. The sample was labeled as G-1-2010.

Pictures of this section of the site are presented in Photographs 22 through 25 in Appendix A. Photograph 25 shows the conditions where sample G-1-2010 was collected.

River Characteristics and Dynamics

The Site is located on a section of the Willamette River that is generally straight to mildly curving. The reach of the Willamette River between RM 4 and 5 is approximately 1,800 feet wide. The eastern portion of the channel is deeper than the western side because of dredging that has occurred in the vicinity of the Port of Portland Terminal 4. This stretch is wider and deeper than the relatively constricted portion of the river between RM 5 and 7.

The following discussion of the Lower Willamette River river hydrology is taken from the April 23, 2004 Programmatic Work Plan for the Portland Harbor RI/FS (Lower Willamette Group, 2004) and the 2009 Draft Portland Harbor RI/FS (Lower Willamette Group, 2009). Figures referenced in the text are provided in Appendix B.

> *The Willamette River is the thirteenth largest river in the contiguous United States in terms of discharge, averaging about 40,000 cfs. Flows are highly variable, however, both seasonally and year-to-year as a function of rain and snowpack levels in the region. Discharge typically varies seasonally by a factor of 10, with late-summer, dry-season levels at or below 10,000 cfs and rainy season December/January averages that approach and periodically exceed 100,000 cfs. Thirteen federal dam/reservoir systems on the upper Willamette River and its tributaries are used to stabilize river flow by storing water in the winter months and releasing it in the summer. Nonetheless, discharge events approaching 200,000 cfs occur every few years, and exceptionally large precipitation events can still result in major floods. The February 1996 event nearly flooded downtown Portland as the Willamette River discharge exceeded 400,000 cfs (40–50 times greater than typical low-flow levels). This combination of river regulation, high seasonal flow variability, and high levels of anthropogenic activity within the Study Area results in potentially complex and variable sediment transport dynamics over time.*
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> *Figure 3.3-1 shows a plot of the mean daily river stage data from October 1, 1972 through March 31, 2008 at the Morrison Bridge in Portland near RM 12.8 (reported in feet PRD, USGS gauge #14211720).[2] Mean historical daily discharge (cfs) calculations from this gauge are shown in Figure 3.3-2.*

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2 *Data obtained from Regulation and Water Quality Section Web site (http://www.nwd-wc.usace.army.mil/perl/dataquery.pl?k=id:PRTO+record://PRTO/HG//1DAY/MEAN/) and the USGS National Water Information System Web site (http://waterdata.usgs.gov/or/nwis/uv?14211720). Where USGS data are available, they replaced USACE data for compiling the graphs shown in this section. The USACE site notes that these "data have not been verified and may contain bad and/or missing data and are only provisional and subject to revision and significant change." The data are used here only to illustrate long-term relative trends in the Willamette River stage at Portland. No data are available for 1991 and 1992.*

3 *A water year extends from October 1 to September 30 (e.g., October 1, 1972 to September 30, 1973 comprises the 1973 water year).*

HEC-RAS Model

A HEC-RAS model for the lower Willamette River was obtained from the City of Portland. The HEC-RAS model obtained was developed for the Flood Insurance Study prepared by the Federal Insurance Administration (FIA) under agency agreement with the Portland District US Corps of Engineers (USACE). In addition to being used to evaluate flood elevations associated with a variety of recurrence intervals (10-, 50-, 100-, and 500-year flood events) the model can be used to evaluate stream velocities within the Willamette River.

The latest version of the model was revised October 19, 2004. The HEC-RAS model was developed by the USACE Hydrologic Engineering Center for modeling water surface profiles and stream flow velocities for various flood events. An existing cross section at RM 4.54, was used to evaluate flow and river stage at the site for flood events with return intervals of 10-, 50-, 100-, and 500-years (annual probability of occurrence of 10, 2, 1, and 0.2 percent).

Results of the HEC-RAS model evaluation are presented in Table 1.

Table 1
Summary of HEC-RAS Model River Flow Characteristics
Willamette River, RM 4.54

Flood Event	Total River Flow (cfs)	Water Surface Elevation (ft)	Water Velocity at Left Outer Bank (ft/s) (cm/s)	Average Water Velocity (ft/s) (cm/s)
10-year	153,000	24.64	0.04 (1.22)	1.40 (42.67)
50-year	272,000	28.81	0.16 (4.88)	2.32 (70.71)
100-year	375,000	29.24	0.24 (7.32)	3.18 (96.93)
500-year	447,000	34.10	0.38 (11.58)	3.51 (106.98)

cfs = cubic feet per second
lbs/ft2 = pounds per square foot
ft/s = feet per second
cm/s = centimeters per second

Results of the HEC model show that the water surface elevation during flood events will be flowing along the river bank at the site. As expected, the average water velocities in the Willamette River at the site increase with increasing magnitude of the flood event. The greatest water velocity will occur in the deepest portions of the river channel and will decrease with decreased water depth and an increased roughness of the river bottom or bank. The magnitudes of water velocity shown at the left bank (west side/project side) of the Willamette River are very low and are a function of the shallow water and the roughness of the bank area. Average water velocities for the entire channel are shown for comparison.

River Bank Grain Size Sampling

Samples of river bank material were collected at four locations where riprap armoring was visibly absent from the bank surface where bank material is most likely to be susceptible to erosion. Two, one-gallon sealable plastic bags were collected at each location. Sieve analysis on each individual bag of material was performed by Northwest Testing, Inc. of Wilsonville, Oregon to determine grain size distribution. Testing two bags of material for each sample location allowed for assessment of the variability of grain size. The variability of grain size from each of the two bags of material collected at each sample location was not significant. Therefore, the combined analysis between the two bag samples has used for evaluating erosion potential at each location. Sampling locations were numbered G-1-2010 through G-4-2010 and collected at Stations 10+05, 6+45, 4+35, and 1+30, respectively. Locations of the sample collection points are shown in Figure 4A and 4B.

Complete results of the sieve analyses are presented in Appendix C of this TM. The distribution of grain size for each sample location (combined results from tests on two bag samples), including the average grain size is shown in Table 2.

Table 1
Summary of Grain Size Analyses
River Bank Soil Samples

Sample No.	Station Location	Gravel (%)	Sand (%)	Fines Content (%)	Average Grain Size	
					millimeters	Inches
G-1-2010	10+05	43	55.5	1.5	2	0.08 (#10 sieve)
G-2-2010	6+45	70	28.6	1.4	18	¾
G-3-2010	4+35	58	30.1	11.9	12	½
G-4-2010	1+30	71.5	18.7	9.8	35	1 ⅜

Fines content is the percent, by weight of the sample passing the US No. 200 sieve

Analyses and Discussion

River Currents and Sediment Transport

An analysis of river currents was performed to determine the size of non-cohesive sediment grains that could be transported under various flood conditions. This analysis allows for developing an understanding of the size of river bank materials that could be transported by river currents during flood events.

River current velocities were calculated using the HEC-RAS model supplied by the City of Portland. The model yields an average water velocity for the cross section analyzed as well as near bank velocities, referred to as outer bank velocities.

The HEC-RAS model is a 2-dimensional model with limitations on the accuracy of predicting flow distributions across any individual river section. In order to evaluate potential for erosion, a stream velocity along the river bank equal to 50 percent of the average water velocity has been used. Using 50 percent of the average river velocity results in evaluating erosion potential with a much higher water velocity (five to twenty times higher) than those reported in Table 1 for the outer bank area. Fifty percent of the average water velocity was used because of the limitation in the HEC-RAS model of predicting very accurate velocity distribution over the entire river cross section. The values of water velocity utilized for assessing erosion potential due to river currents are 21.3, 35.3, and 48.5 cm/sec for the 10-, 50-, and 100-year flood events.

Stream velocities for the 10-, 50-, and 100-year flood events are plotted on the Hjulström Diagram in Figure 5. This diagram shows a plot of grain size versus mean water velocity for the sedimentation, transportation, and erosion of non-cohesive sediments. The diagram was developed based on current speeds 1-meter above the sediment bed, but provides approximate grain sizes that will be transported using the river current velocities discussed herein. Figure 5 suggests that erosion of even fine-grained bank soil due to river currents is not anticipated for less than the 10-year flood event. For the 100-year flood event, bank material consisting of coarse sand/very fine gravel to silt may be subject to erosion. On the bases of these results, the potential for river bank erosion due to river currents appears to be low except for flood events greater than the 50-year event.

Wind Generated Waves

In order to assess erosion potential for wind-generated waves at the site, a sustained wind speed of 40 mph traveling over a fetch length of 0.6 miles has been used to evaluate the significant wave height. Significant wave height is the average height of the highest one-third of all the waves in a wave train that is used in the design of bank protection. The 40 mph wind speed is associated with a 2-year return-period wind event in the Portland metropolitan region. A detailed discussion of wind speed and wind direction based on information from the NOAA, National Weather Service Forecast Office for the Portland International Airport for the period between 1948 and 1995 is contained in Appendix D along with a figure (Figure D-1) showing a wind speed contour map for western Oregon.

While procedures for predicting wind-generated waves are complex, a simplified wind wave prediction technique is often used to determine the adequacy of slope protection, especially for non-ocean sites. An estimate of wind-generated significant wave heights is made using a nomographs from the USACE Shore Protection Manual (USACE, 1984) shown in Figure 6.

The resulting significant wave height for 40 mph wind velocity over a fetch length of 0.6 miles is 1.3 feet.

A relationship that may be used to evaluate the size of riprap required to resist wave erosion is given by the following equation:

$$D_{50} = 0.75\ H/(\cos 1/3\ \theta)$$

where,

D_{50} = Median Riprap Size (feet)

H = Significant wave height (feet)
θ = Slope of bank with respect to horizontal

A nomograph showing the results of this equation is provided in Figure 7. As shown on the figure, the required median size of riprap needed to withstand erosive forces due to wind generated waves having a height of 1.3 feet would be about 0.45, 0.50, 0.58, and 0.75 feet diameter for bank slopes of 4H:1V, 3H:1V, 2H:1V, and 1H:1V, respectively. Using a specific weight of 2.65 for the stone, these stone dimensions are equivalent to median riprap weights of about 9, 12, 20, and 40 pounds.

This evaluation shows that the required median riprap size required to resist wave erosion is dependent on the angle of the river bank upon which the wave is impacting. For bank angles flatter than 3H:1V the required average riprap size is about 6 inches diameter. For bank as steep as 1H:1V, the average size of riprap required is 9 inches diameter.

In general the riprap armorning present along the river bank at the site meets or exceeds the riprap dimensions required to prevent erosion from wind generated waves of up to about 1.3 feet. However, there are some areas where this is not the case. Predominantly these areas exist near the top of the slope between approximate elevation 25 and 30 feet in areas where the bank is sloped steeper than 1.5H:1V. In these areas, the analysis suggests that the bank would be subject to erosion from waves. This condition would only be possible during a flood event with a recurrence interval of 10 years or more.

Boat Generated Waves

Evaluation of boat generated waves is based on observation at the project site. The largest boats that travel on the Willamette River near the site are large ships that typically are travelling to nearby port facilities. Barges and tug boats also pass the site. However, the largest boat generated waves have been observed to originate from larger recreation boats that travel at a higher rate of speed.

Based on observations at the site, the largest boat generated waves that would reach the river bank are about 18 inches in height, similar to the significant wave height determined for wind-generated waves. It should be noted that boat speeds on the river will generally decrease during flood events because of the potential for floating debris in the water. Therefore, the size of riprap required to resist erosion from wind-generated waves is expected to control.

Surface Water Runoff and Precipitation

Areas of erosion from surface water runoff were observed during site visits conducted on May 25, July 7 and November 8, 2010 . Light rain fell on November 8th but it was insufficient to result in runoff. A trace (0.01 inches) of precipitation was reported by the National Weather Service for Portland, Oregon on November 8, 2010. The National Weather Service reported 0.38 inches of rainfall for May 25, 2010. Rainfall totals were 0.2 inches or greater for five of the six days preceding this site visit. Precipitation was observed to infiltrate into the gravel surfacing present at the top of the river bank during this site visit. No stormwater runoff over the river bank was observed.

The gravel surfacing that covers the ground above the top of the river bank at the site limits the potential for overland flow of precipitation and collection of surface water into concentrated flows. However, observation of existing site conditions identified two areas where there are signs of river bank erosion due to surface water runoff. The first is located from approximate Station 0+10 to 0+30 near the north end of the project site river bank. The second location is between approximate Stations 9_70 and 10+20 near the south end of the project site.

Downspouts from the roof of Warehouse C drain to the top of the river bank slope at approximate Stations 3+70 and 4+55. Additionally, two outfalls discharge to the river bank, one at Station 1+68 and the other at Station 5+95. There are no signs of significant erosion at any of these locations.

Mass Wasting

One area was observed to have the potential for minor slumping during site observations performed in September and November 2010. The area is located at the north end of the site between Station 0+00 and 0+50 where it appears that rubble fill was end dumped along the bank. The rubble fill consists of concrete rubble with cobbles, gravel, and soil. The material does not appear to be well compacted. The existing river bank is sloped at about 1.4H:1V with the height of the steep portion being about 14 feet. Some support of material near the bottom of the slope is being provided by timber pile that were part of the lower bulkhead in the area.

It's beyond this scope of this work to evaluate the stability of this section of slope. However, based on the visual observations of the material, it is reasonable to expect that some slumping of the river bank could occur, especially with additional weathering or damage to the dilapidated timber pile near the bottom of the slope. If the timber pile fail, it is reasonable to expect that the bank materials will seek a more stable slope configuration that could be closer 2H:1V. This would result in a flattening of the slope from material near the top of the bank sliding away and being deposited near the toe until a stable configuration is obtained. However, because of the loss of property used for Kinder Morgan operations, it is expected that if significant mass wasting were to occur, Kinder Morgan would address the issue with repairs to the bank.

Conclusions

This assessment to evaluate erosion potential at the site suggests that the potential for erosion of river bank material from river currents is very low. In most areas riprap armoring stone covers the river bank and has sufficient size and depth to prevent erosion from river currents. In areas where the armoring stone is not present at the surface minor erosion could occur during large flood events having recurrence intervals of greater than 50 years. Even during these flood events, the materials that may be subject to erosion range between silts and coarse sands to fine gravels. Of the four samples of bank material collected at the site, the lowest percentage of gravel contained was 43 percent. As the finer material were removed by erosion, the coarser gravels present would begin to naturally armor the surface and minimize the depth of erosion. For this reason, it is expected that the depth of potential erosion due to river currents along the river bank would be low, even during a large flood.

A reasonable assumption of the maximum depth of erosion due to river currents would be about 1 foot.

The assessment to evaluate the potential for erosion of river bank material due to wind-generated waves was completed assuming a 2-year wind storm occurs at the same time that a flood event is occurring. The resulting significant wave height was determined to be about 1.3 feet. Even though a significant dock structure protects much of the river bank, no reduction in wave height was taken. The size and weight of riprap stone required to resist erosion forces of these waves were calculated for a variety of bank angles ranging from 4H:1V to 1H:1V. The results show that riprap with a median size of 6 inches is acceptable for bank slopes up to about 4H:1V. Eight inch diameter riprap would be acceptable for bank slopes up to about 2H:1V and riprap with a median diameter of at least 9 inches is required for slopes steeper than 1.5H:1V.

The riprap armoring present along the river bank at the site meets or exceeds the riprap dimensions required to prevent erosion from wind generated waves of up to about 1.3 feet in most areas. However, near the top of the slope between approximate elevation 25 and 30 feet, there are a few areas that are sloped at about 1.5H:1V or steeper where the larger riprap stones are no longer protecting the bank. There is a potential for bank erosion in these areas during flood events exceeding the 10-year recurrence interval.

It would not be possible to determine the depth of potential wave erosion at the site without a much more detailed assessment that is not warranted for this site. However, it's not likely that high winds would persist more than a few hours. Erosion rates would reduce quickly with lessening wind speeds. Additionally, the bank soils appear to have sufficient intermixed cobbles and boulders that some natural armoring would be expected as finer grained soil and gravel are washed away from the bank. At a worst case scenario, the tops of the river banks could erode until the upper portion of the bank has eroded to a more stable slope. In many areas a timber pile and lagging bulkhead would be exposed and would prevent further erosion from occurring.

Bank erosion due to boat generated waves would be less than that associated with wind-generated waves. Although the larges boat generated waves are expected to be about the same size as the wind-generated waves evaluated, the waves would strike the river bank for a much shorter time period.

There are two areas where minor erosion appears to be occurring because of surface water runoff. Minor grading at the top of the river bank and placement of additional surface gravel could be performed to prevent future erosion in these areas.

Recommendations

Based on the erodible soil analysis, areas currently without riprap protection could be subject to erosion up to about one foot. These areas were sampled for grain size distibuition and additional samples will be collected for analytical testing for the COPC.

Areas with riprap protection of insufficient size for the erosion protection depending on the actual bank slope have been identified. Since finer grained sediments are not currently exposed, these areas will not be sampled but will be identified for repair in Source Control Measure Evaluation required for the site.

References

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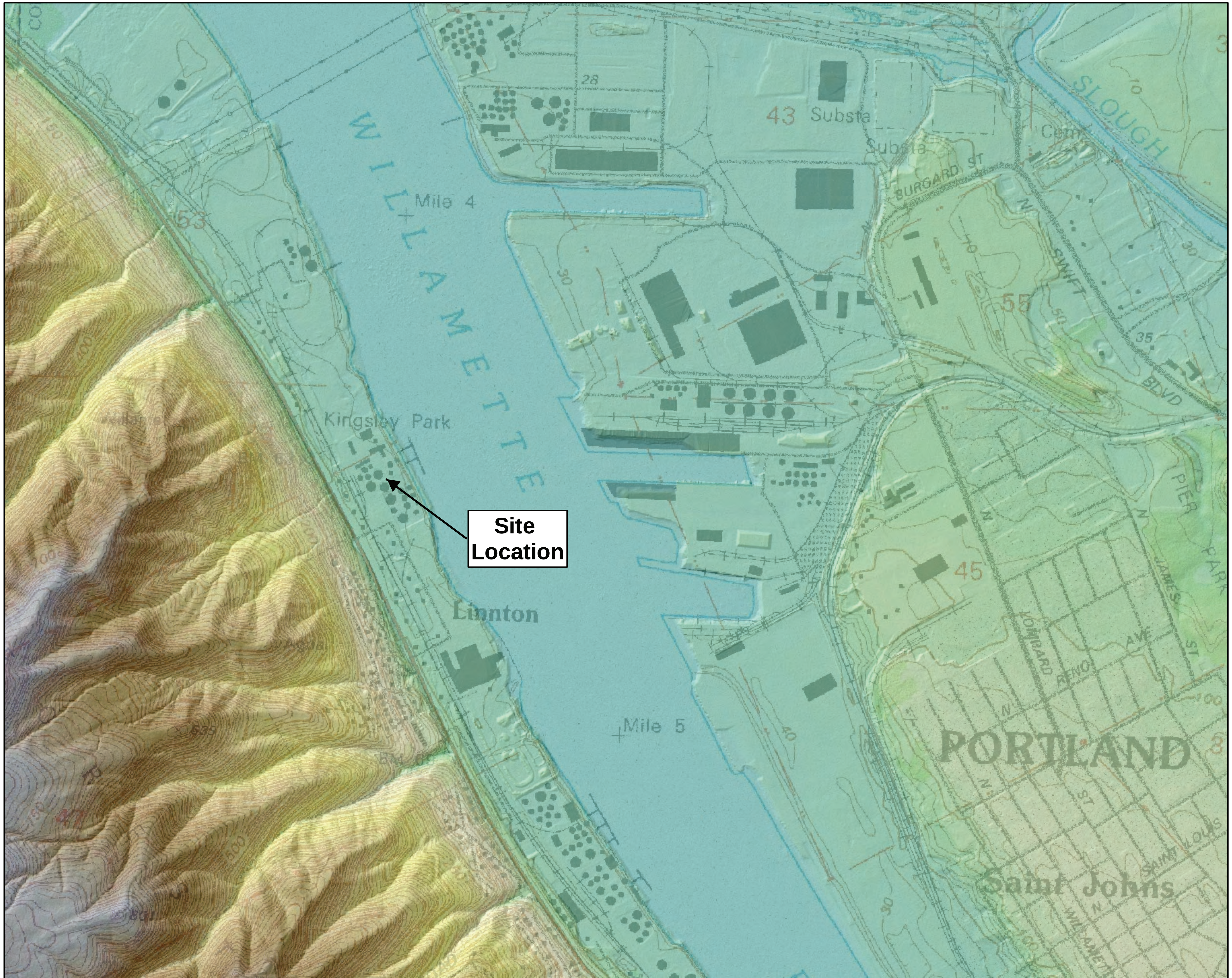
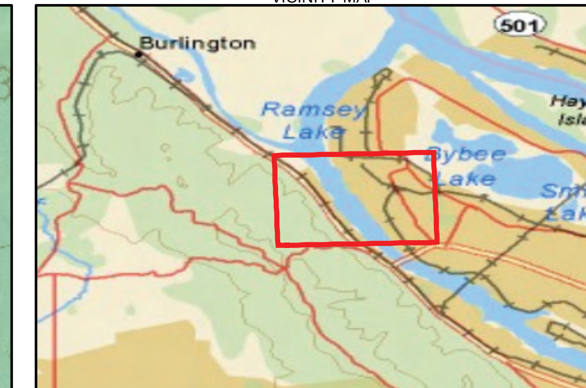


VICINITY MAP



LEGEND

Elevation

High : 1143.87

Low : 7.91

0 500 1,000 1,500

Feet

1 inch = 1,000 feet

FIGURE 1
Site Location Map
Kinder Morgan
Multnomah County, OR

VICINITY MAP

LEGEND

- Site Features
- Fence
- Railroad
- Extent of Bank Soil

Monitoring Wells and Borings

- 3-Foot Diameter Cistern
- Direct Push Boring
- Monitoring Well - Deep
- Monitoring Well - Shallow
- Piezometer
- Recovery Well - Shallow

N

0 37.5 75 150
Feet

FIGURE 2
Site Layout

Kinder Morgan Liquid Terminals LLC
Linnton Terminal
11400 NW St. Helens Road
Portland, Oregon

\\ROSA\PROJ\KINDERMORGAN\405127\GIS\MAPFILES\2010\FIGURE2_SITELAYOUT.MXD GOLDHAM 11/4/2010 12:39:11

CH2MHILL

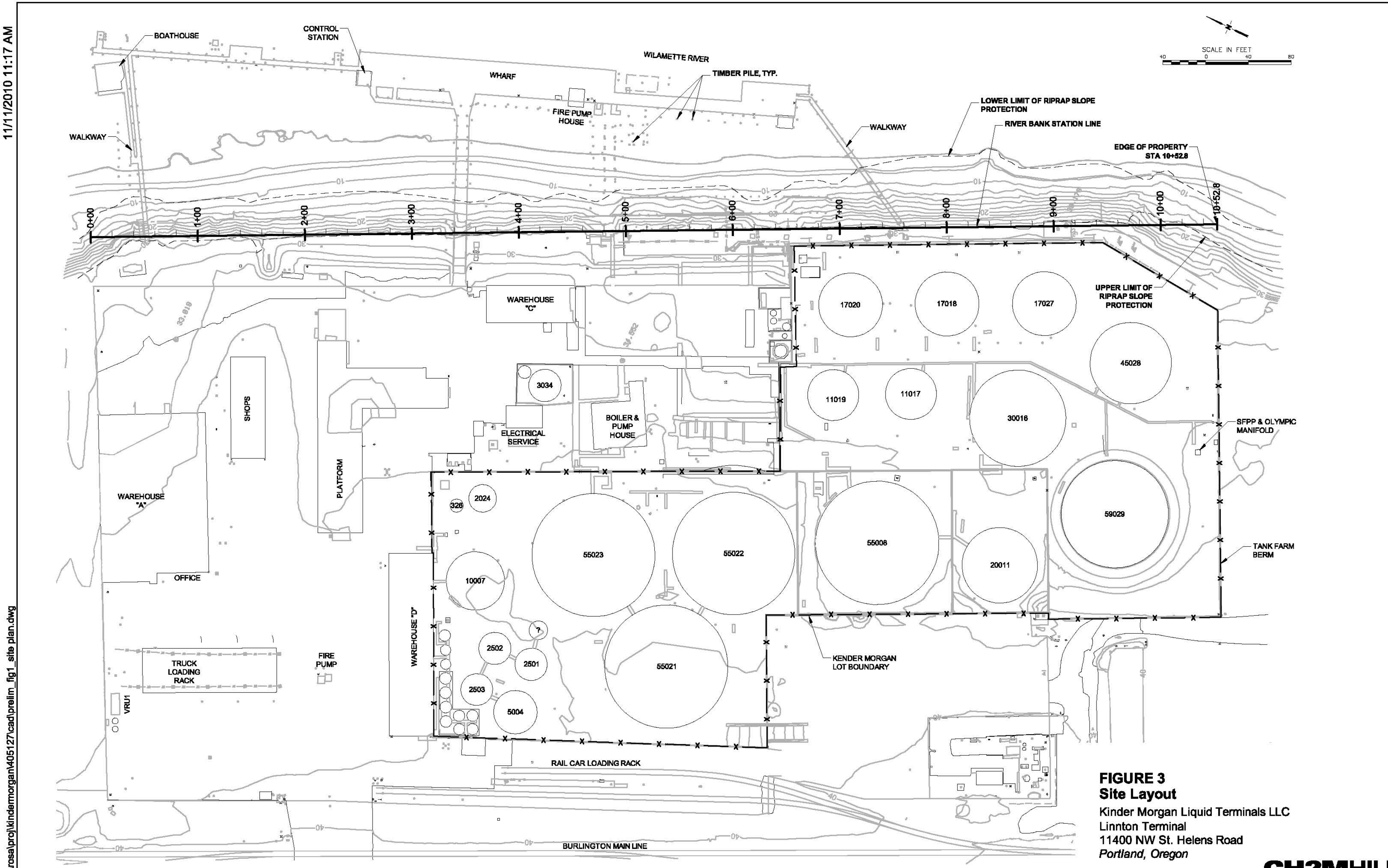


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FIGURE 3
Site Layout

Kinder Morgan Liquid Terminals LLC
Linnton Terminal
11400 NW St. Helens Road
Portland, Oregon

CH2MHILL

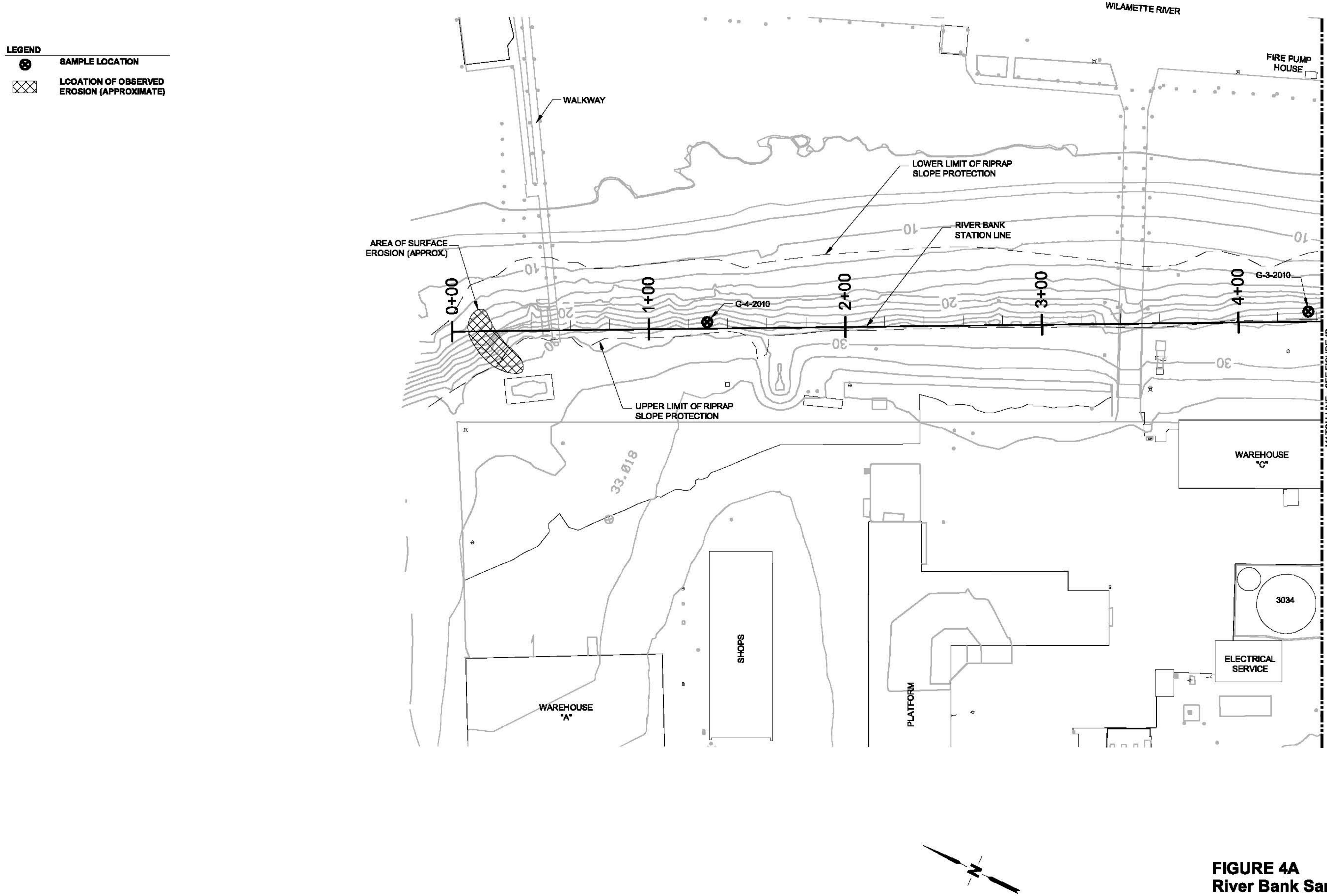

FIGURE 4A
River Bank Sample Locations
Kinder Morgan Liquid Terminals LLC
Linnton Terminal
11400 NW St. Helens Road
Portland, Oregon

CH2MHILL

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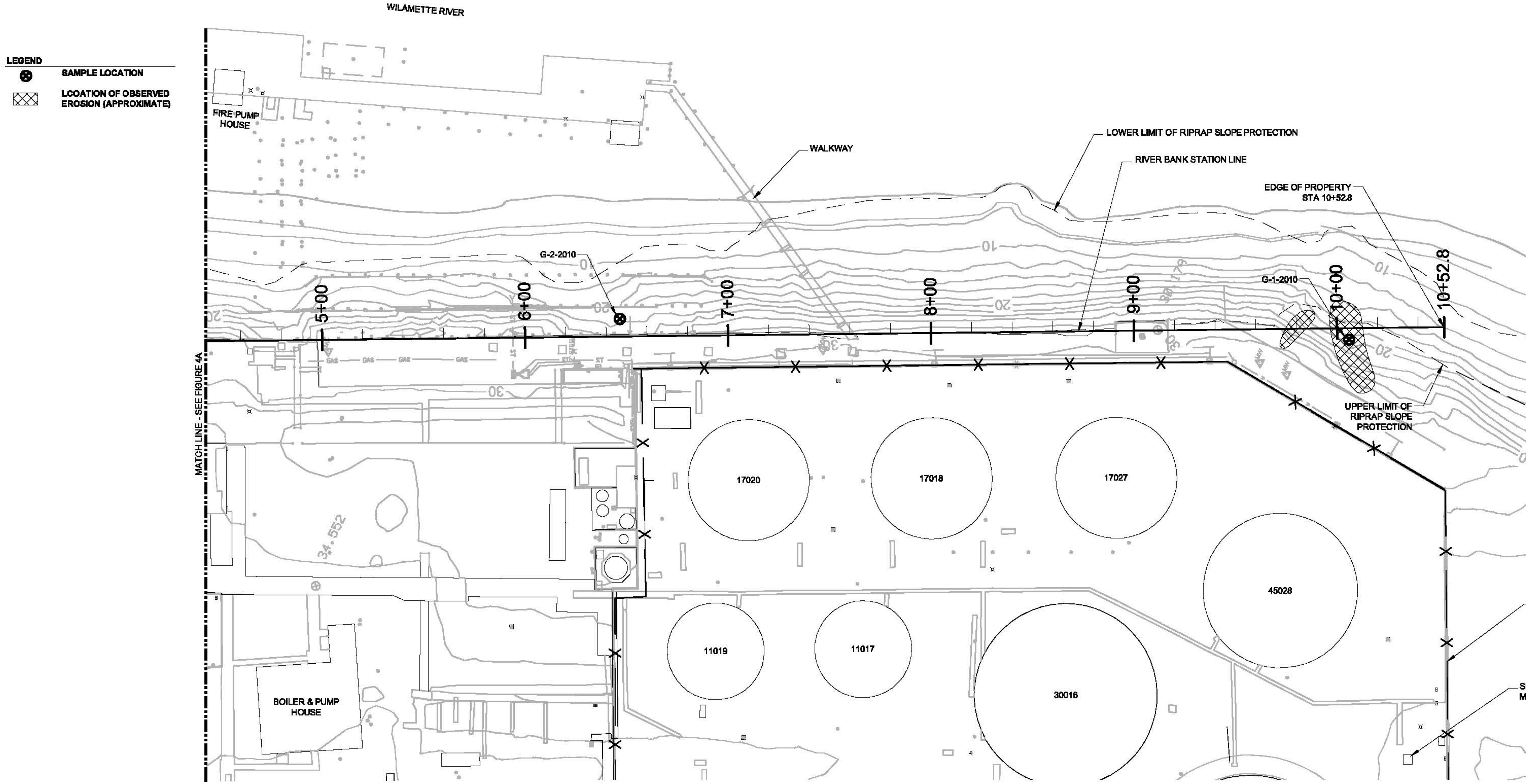

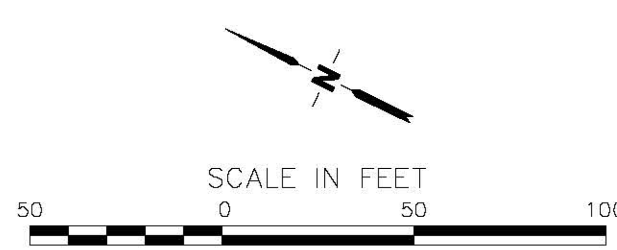

FIGURE 4B
River Bank Sample Locations
Kinder Morgan Liquid Terminals LLC
Linnton Terminal
11400 NW St. Helens Road
Portland, Oregon

CH2MHILL

\\rosa\proj\kindermorgan\405127\cad\prelim_fig1_site plan.dwg

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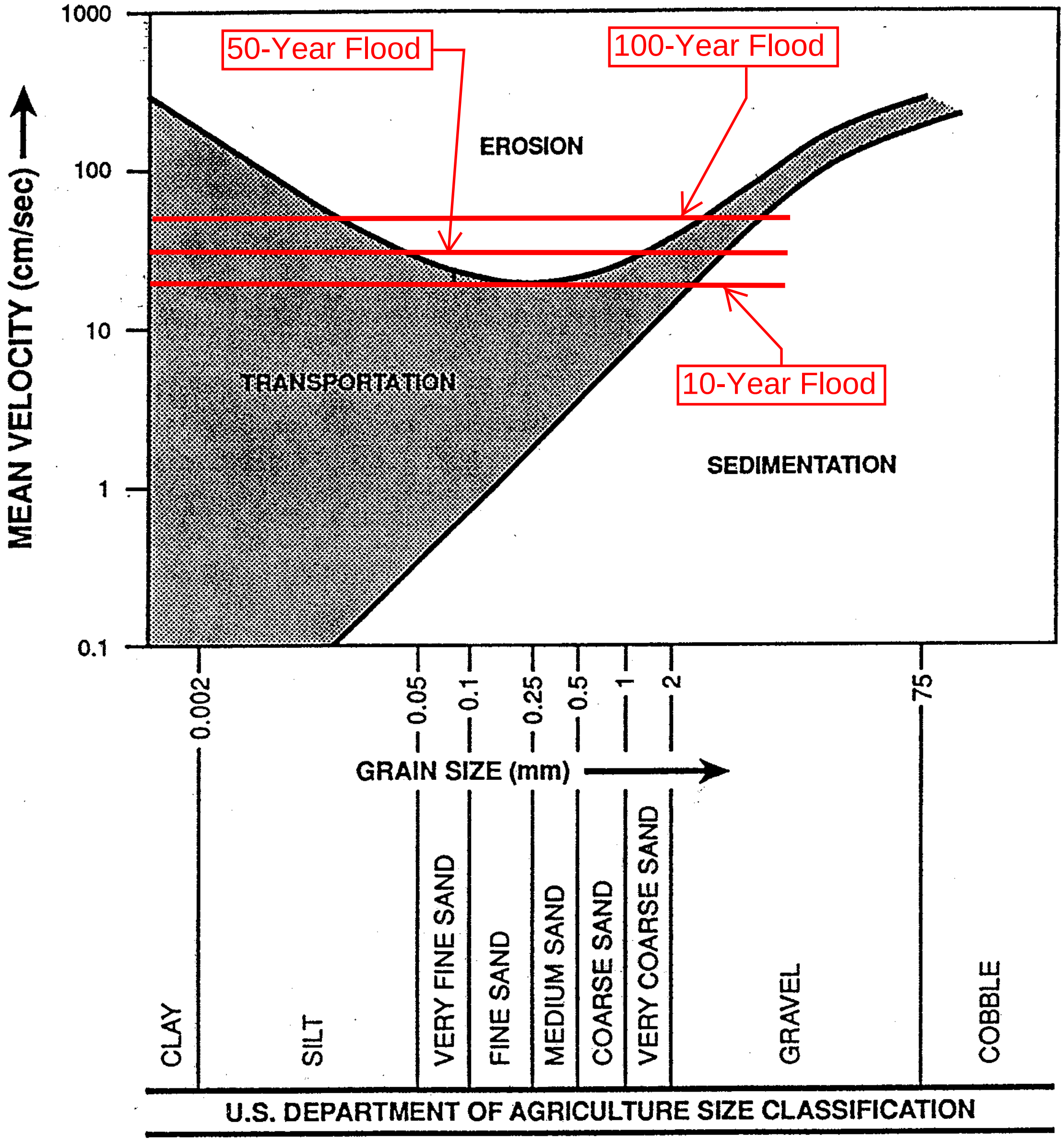
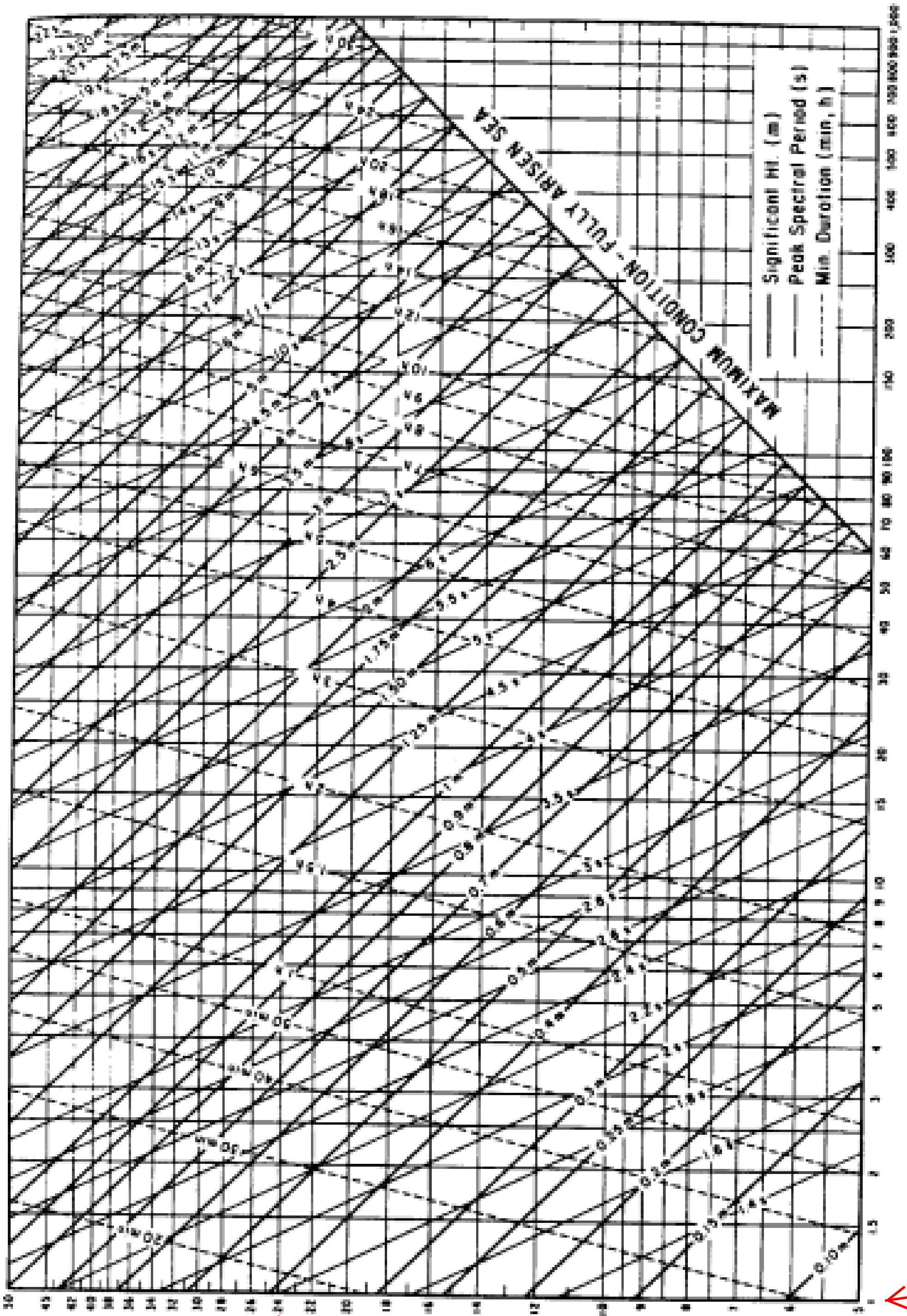


SOURCES: Graf, 1971
Soil Conservation Service, 1972

FIGURE 5
SEDIMENT TRANSPORT REGIMES
BASED ON THE HJULSTRÖM DIAGRAM

FIGURE 6



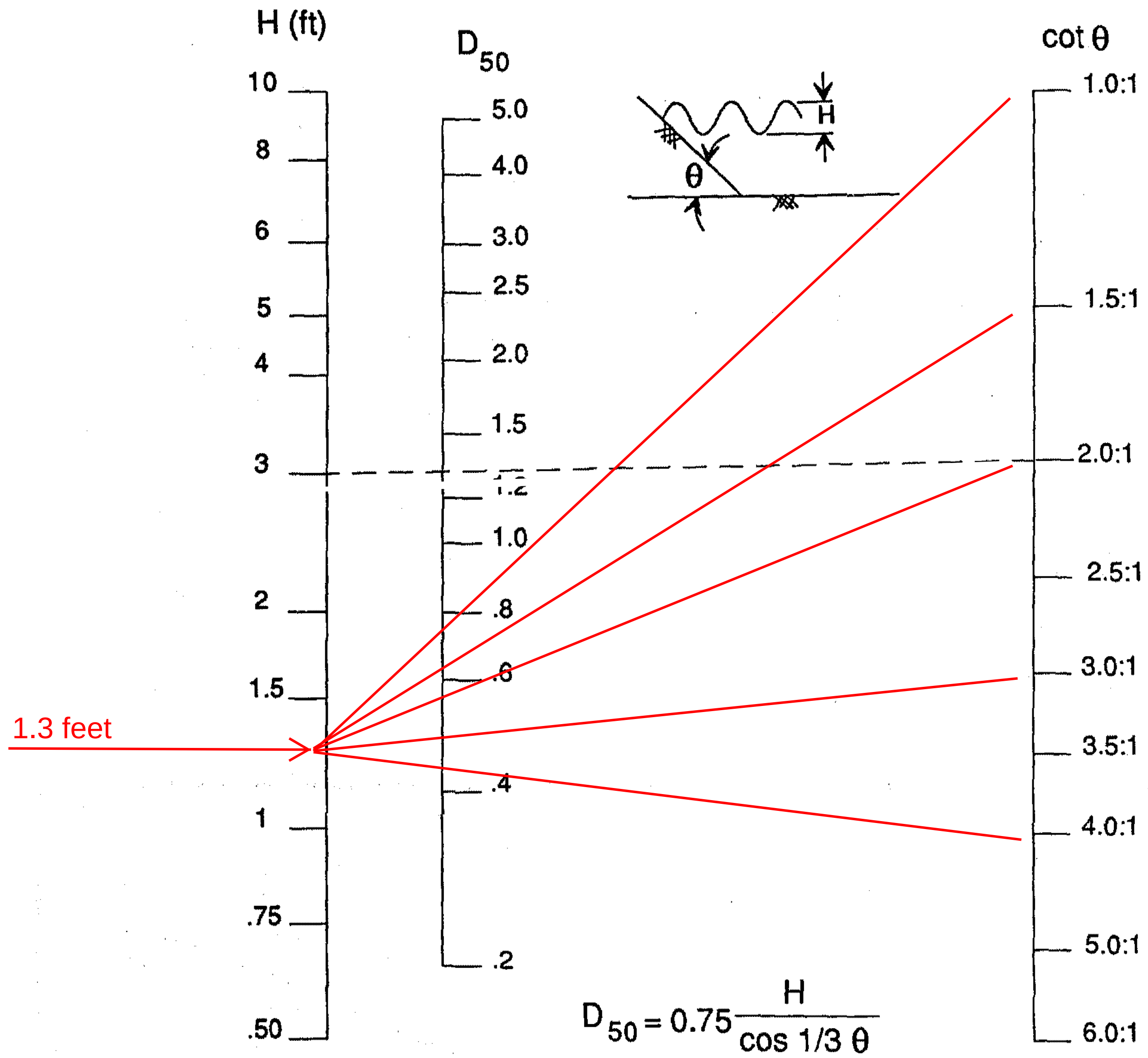
Wind-Stress Factor, U_A (m/s)

U= 40 mph = 17.9 m/s
Wind Stress Factor
(Ua) = 24.6

1 km = 0.6 miles

Estimated significant wave height for 40 mph wind and fetch length of 0.6 miles is 0.4 meters or 1.3 feet.

Figure 7-A-1 Nomographs Of Significant Wave Height Prediction Curves As Functions Of Windspeed, Fetch Length and Wind Duration (Metric units)



$$D_{50} = 0.75 \frac{H}{\cos 1/3\ \theta}$$

D_{50} = Median Riprap Size

H = Wave height

θ = Bank Angle with Horizontal

Chart 7. Hudson relationship for riprap size required to resist wave erosion

FIGURE 7

APPENDIX A

River Bank Photograph Log 2009

Photograph 1: *Dock structure looking east from approximate Station 5+20*

Photograph 2: *Dock structure looking up river from approximate Station 5+20*

Photograph 3: *Station 0+00 to 0+50. Looking down from walkway @ Station 0+50.*

Photograph 4: *Station 0+00 to 0+50 Looking up slope from approximate elevation 10 feet.*

Photograph 5: Station 0+50 to 1+60. Looking south from walkway to dock

Photograph 6: Station 0+75 Looking up bank from bottom of slope.

Photograph 7: Station 1+30 Looking up bank from bottom of slope.

Photograph 8: Collecting grab sample for grain size analyses. Station 1+30.

Photograph 9: Station 2+00. Looking up bank from shore of river.

Photograph 10: Station 4+20. Looking up bank from edge of Willamette River.

Photograph 11: Collecting grab sample for grain size analysis at Station 4+35.

Photograph 12: Looking southwest from top of bank near Station 5+00.

Photograph 13: Looking north from top of bank near Station 6+60.

Photograph 14: Station 5+00 Looking up bank from bottom of slope.

Photograph 15: Station 6+40 Looking northwest from approximate elevation 10 feet.

Photograph 16:Surface conditions near Station 6+80 at approximate elevation 22 feet.

Photograph 17: Surface conditions at location where grab sample G-2-2010 was collected at Station 6+45.

Photograph 18: Surface conditions looking southwest from walkway at Station 7+50.

Photograph 19: Surface conditions looking north from edge of water near Station 9+50.

Photograph 20: Station 6+90 Looking up bank from bottom of slope.

Photograph 21: Station 8+80 Looking up bank from bottom of slope.

Photograph 22: Station 10+40 Looking up bank from bottom of slope.

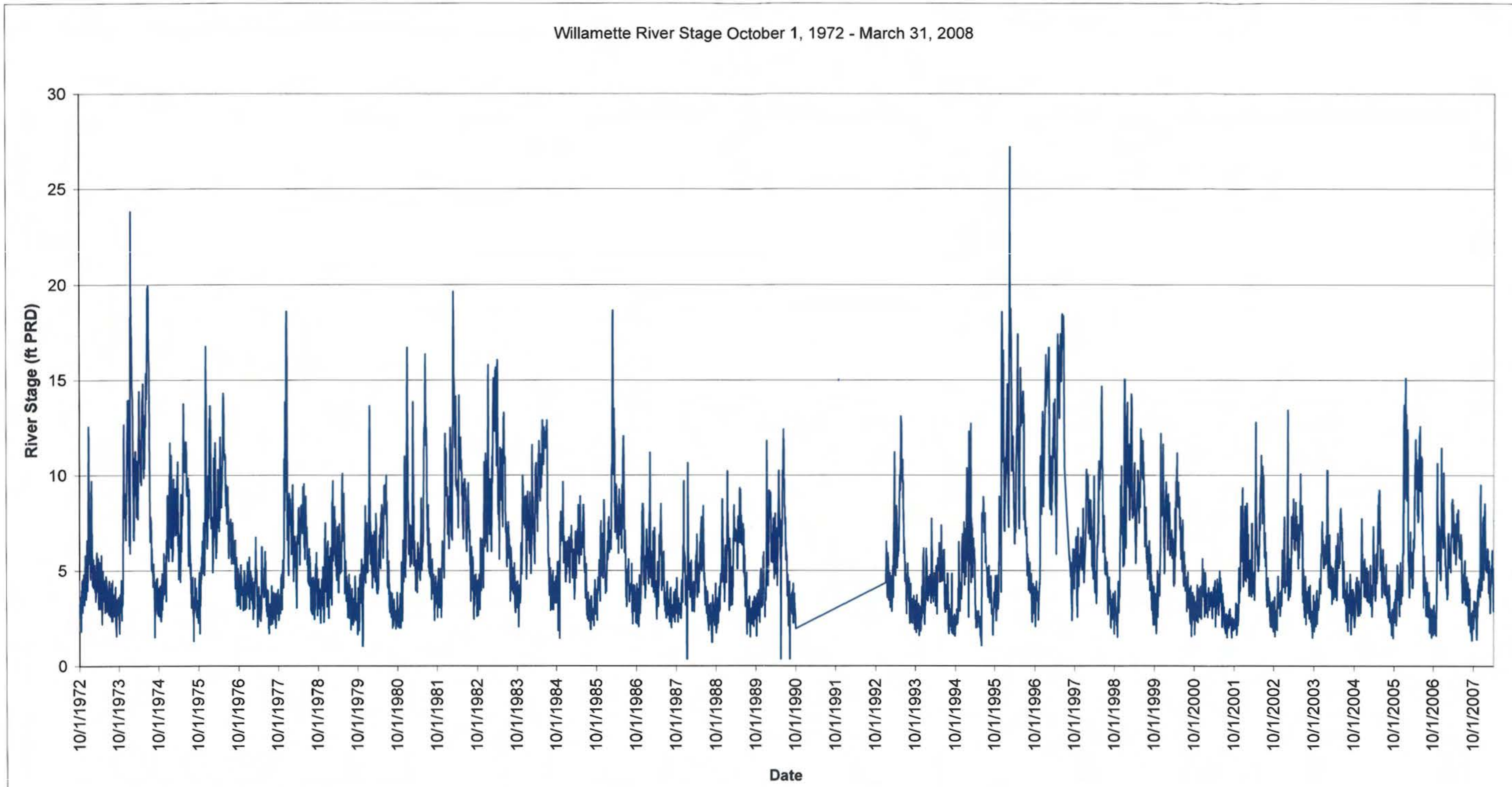
Photograph 23: Station 9+90 Looking up bank from bottom of slope.

Photograph 24: Station 9+70 Looking south from bottom of slope.

Photograph 25: Station 10+05 Surface conditions at location of G-1-2010 sample.

APPENDIX B

Willamette River Flow and River Stage Data: 2009 Draft Portland Harbor RI/FS (Lower Willamette Group, 2009).



Note: Final river stage data was not available from 10/01/1990 through 10/01/1992 from the USGS Real Time National Water Information System (NWIS) Database for the Morrison Bridge station 14211720.

Figure 3.3-1
Portland Harbor RI/FS
Draft Remedial Investigation Report
Willamette River Stage Data,
October 1972 - March 2008

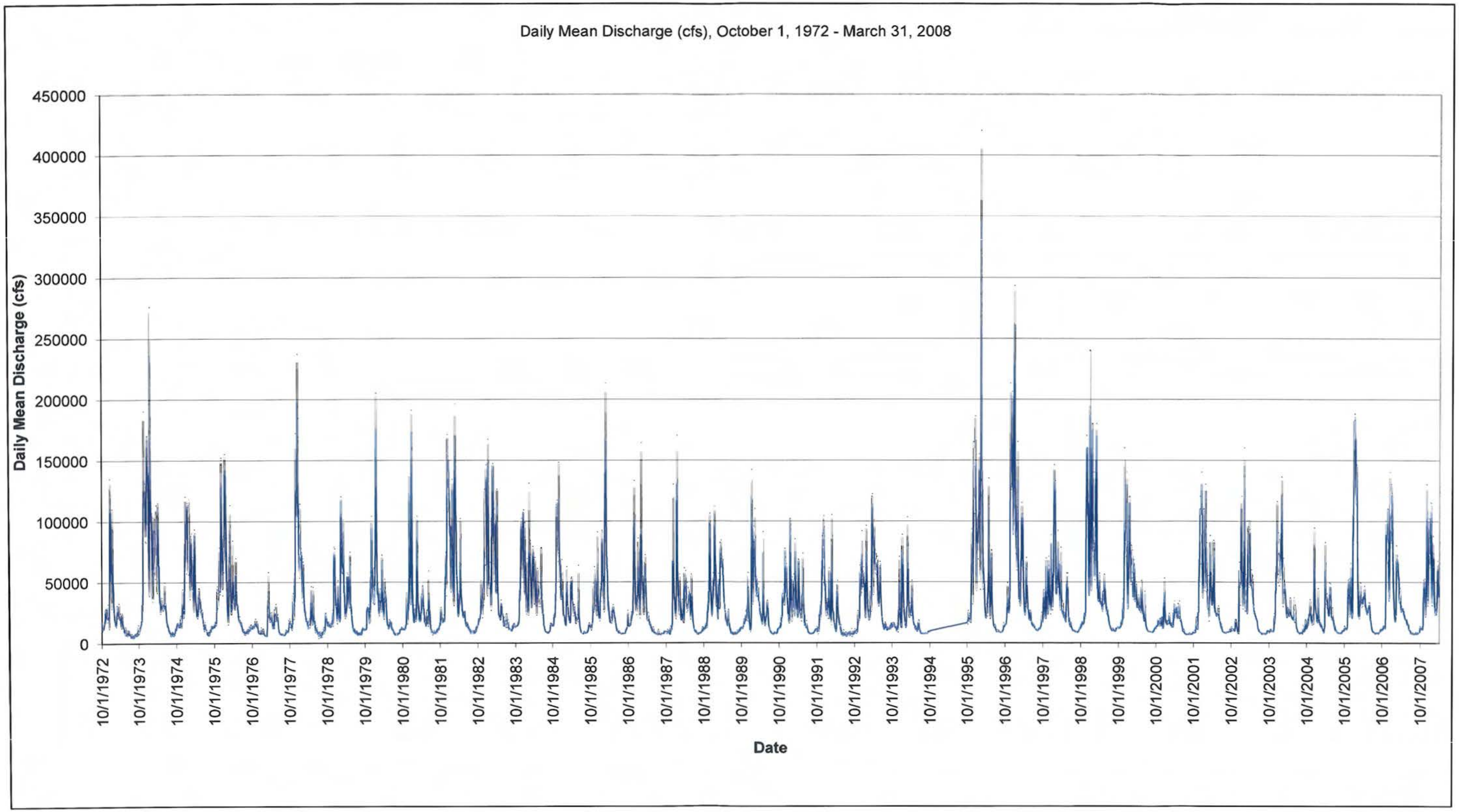


Figure 3.3-2
Portland Harbor RI/FS
Draft Remedial Investigation Report
Daily Mean Discharge (cfs),
October 1, 1972 through March 31, 2008

APPENDIX C

Laboratory Grain-Size Analyses Results.

Northwest Testing, Inc.
A Division of Northwest Geotech, Inc.
9120 SW Pioneer Court, Suite B • Wilsonville, Oregon 97070 503/682-1880 FAX: 503/682-2753

TECHNICAL REPORT

Report To:	Mr. Todd Cotton CH2M HILL, Inc. 2020 SW 4th Avenue Suite 300 Portland, Oregon 97201	**Date:** **Lab No.:**	11/10/10 10-339
Project:	Laboratory Testing – Kinder Morgan Linnton Terminal	**Project No.:**	2139.1.1

Report of: Sieve analyses

Sample Identification

As requested, NTI completed sieve analyses testing of soil on samples delivered to our laboratory on November 8, 2010 by a CH2M HILL, Inc. representative. All testing was performed in general accordance with the methods indicated. Our laboratory's test results are summarized on the following table and attached pages.

Laboratory Test Results

Particle-Size Analysis of Soils (ASTM D422)				
Sieve Size	**G1A 2010 Percent Passing**	**G1B 2010 Percent Passing**	**G2A 2010 @ 0 – 4" Percent Passing**	**G2B @ 4 – 8" Percent Passing**
6"	100	100	100	100
3"	100	100	100	78
2"	94	91	79	78
1 ½"	87	88	70	71
1"	76	80	59	57
¾"	71	74	54	51
½"	64	67	45	40
⅜"	59	64	40	35
¼"	55	60	33	27
#4	53	58	28	23
#8	50	55	20	16
#10	49	54	19	15
#16	47	52	16	12
#30	41	46	9	8
#40	34	38	6	6
#50	19	21	4	4
#100	4	3	2	2
#200	2.0	1.1	1.4	1.4

Attachments: Laboratory Test Results
Gradation Test Results

Copies: Addressee

 REVIEWED BY: Bridgett Adame BA

Northwest Testing, Inc.
A Division of Northwest Geotech, Inc.
9120 SW Pioneer Court, Suite B • Wilsonville, Oregon 97070 503/682-1880 FAX: 503/682-2753

TECHNICAL REPORT

Report To: Mr. Todd Cotton
CH2M HILL, Inc.
2020 SW 4th Avenue Suite 300
Portland, Oregon 97201

Date: 11/10/10

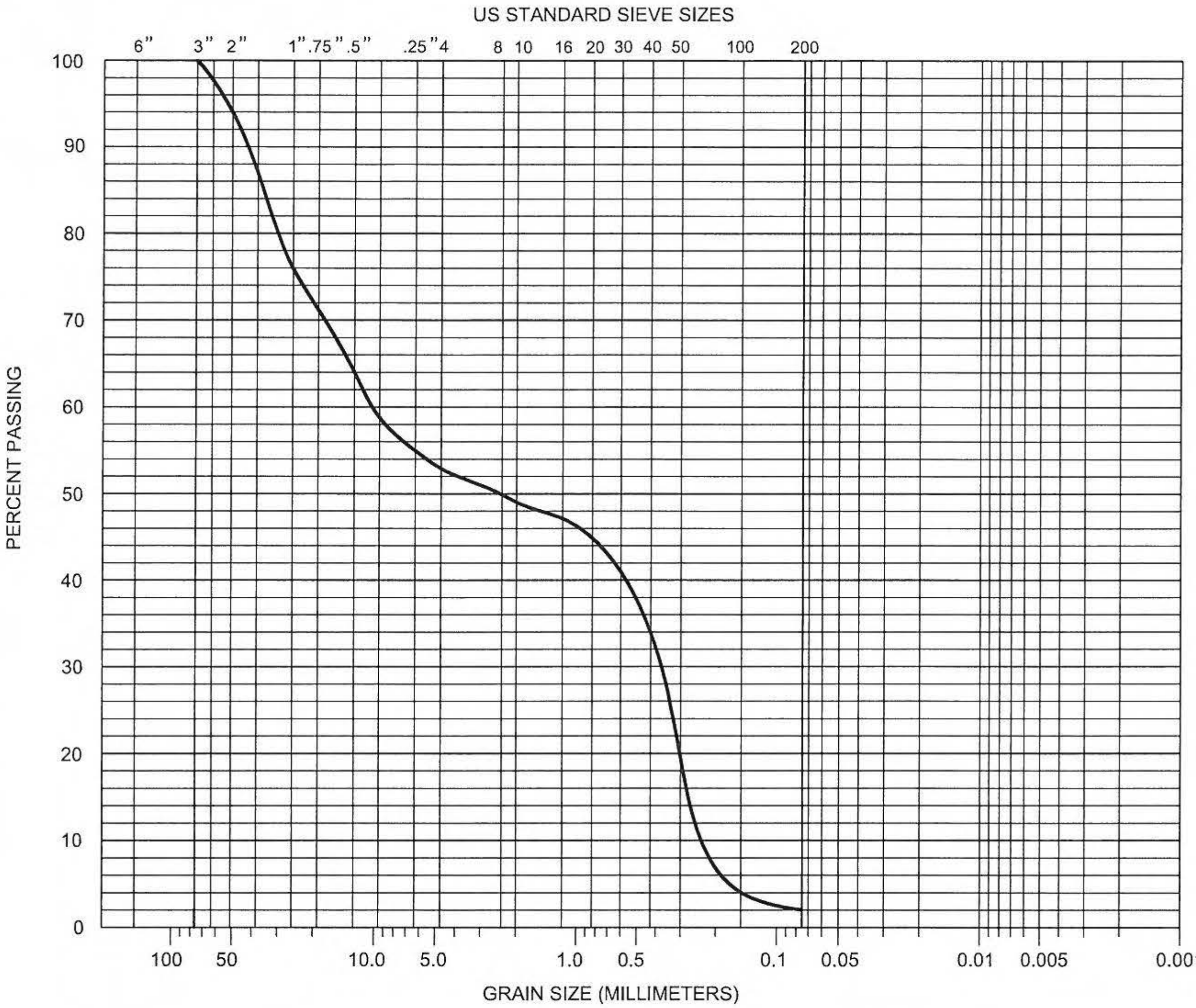
Lab No.: 10-339

Project: Laboratory Testing – Kinder Morgan Linnton Terminal

Project No.: 2139.1.1

Laboratory Test Results

Particle-Size Analysis of Soils (ASTM D422)				
Sieve Size	**G3A 2010 Percent Passing**	**G3B 2010 Percent Passing**	**G4A 2010 Percent Passing**	**G4B 2010 Percent Passing**
6"	100	100	100	100
3"	82	100	100	76
2"	82	92	76	50
1 ½"	77	74	62	48
1"	68	61	57	39
¾"	63	55	51	36
½"	57	47	45	28
⅜"	54	43	41	25
¼"	47	38	35	22
#4	42	35	32	20
#8	35	29	25	16
#10	34	28	24	16
#16	30	26	22	14
#30	26	22	19	13
#40	24	20	19	12
#50	21	18	18	11
#100	17	14	15	10
#200	13.1	10.6	12.1	7.4



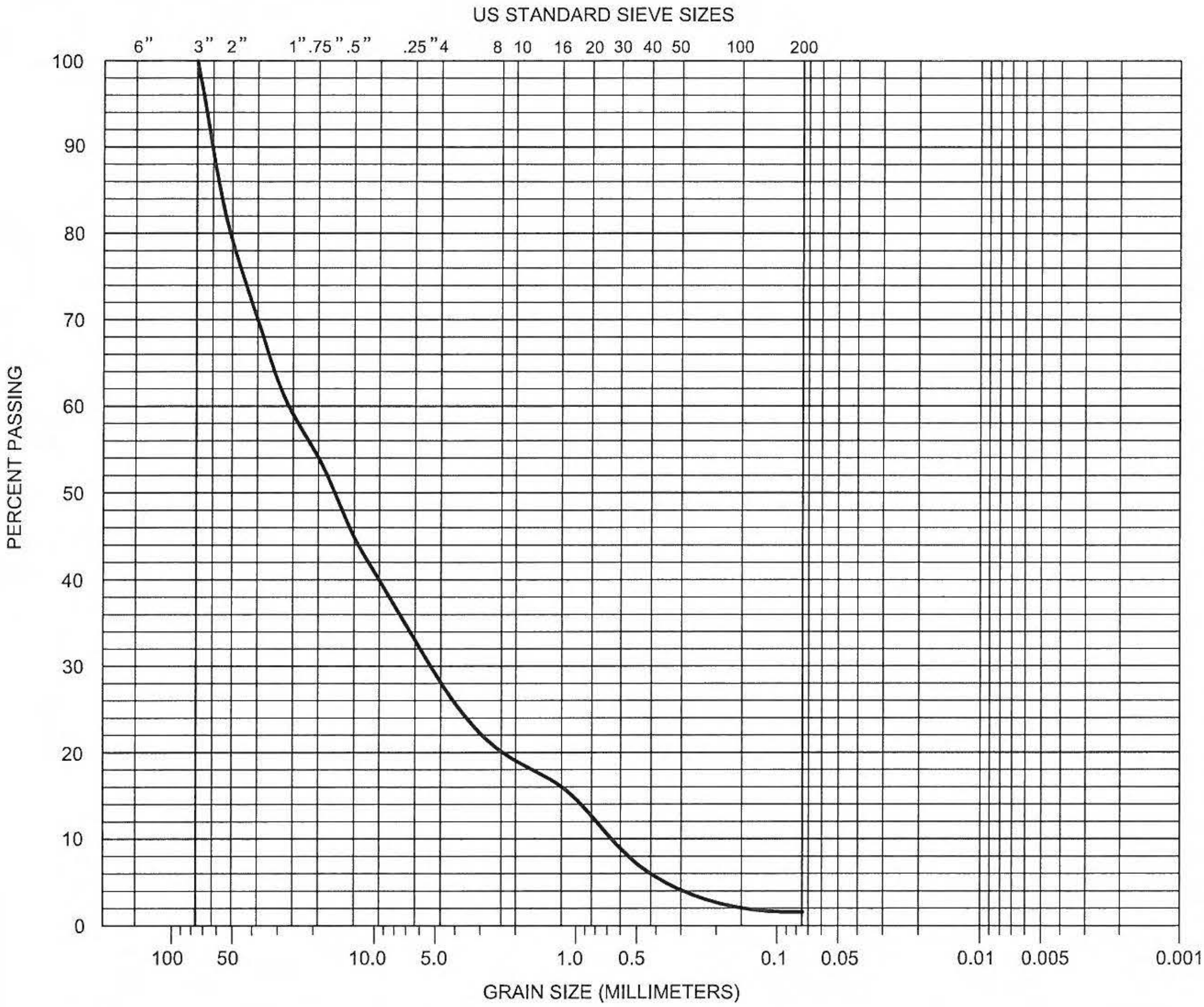
COBBLES	GRAVEL		SAND			SILT AND CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	

SYMBOL	SAMPLE LOCATION	FIELD MOISTURE (%)	% PASSING NO. 200 SIEVE	% PASSING 2 μ	UNIFIED SOIL CLASSIFICATION
———	G1A 2010	--	2.0	--	--

GRADATION TEST RESULTS – ASTM D422

PROJECT NO. 2139.1.1	CH2M HILL KINDER MORGAN LINNTON TERMINAL LABORATORY TESTING	LAB NO. 10-339

Northwest Testing, Inc.
A Division of Northwest Geotech, Inc.



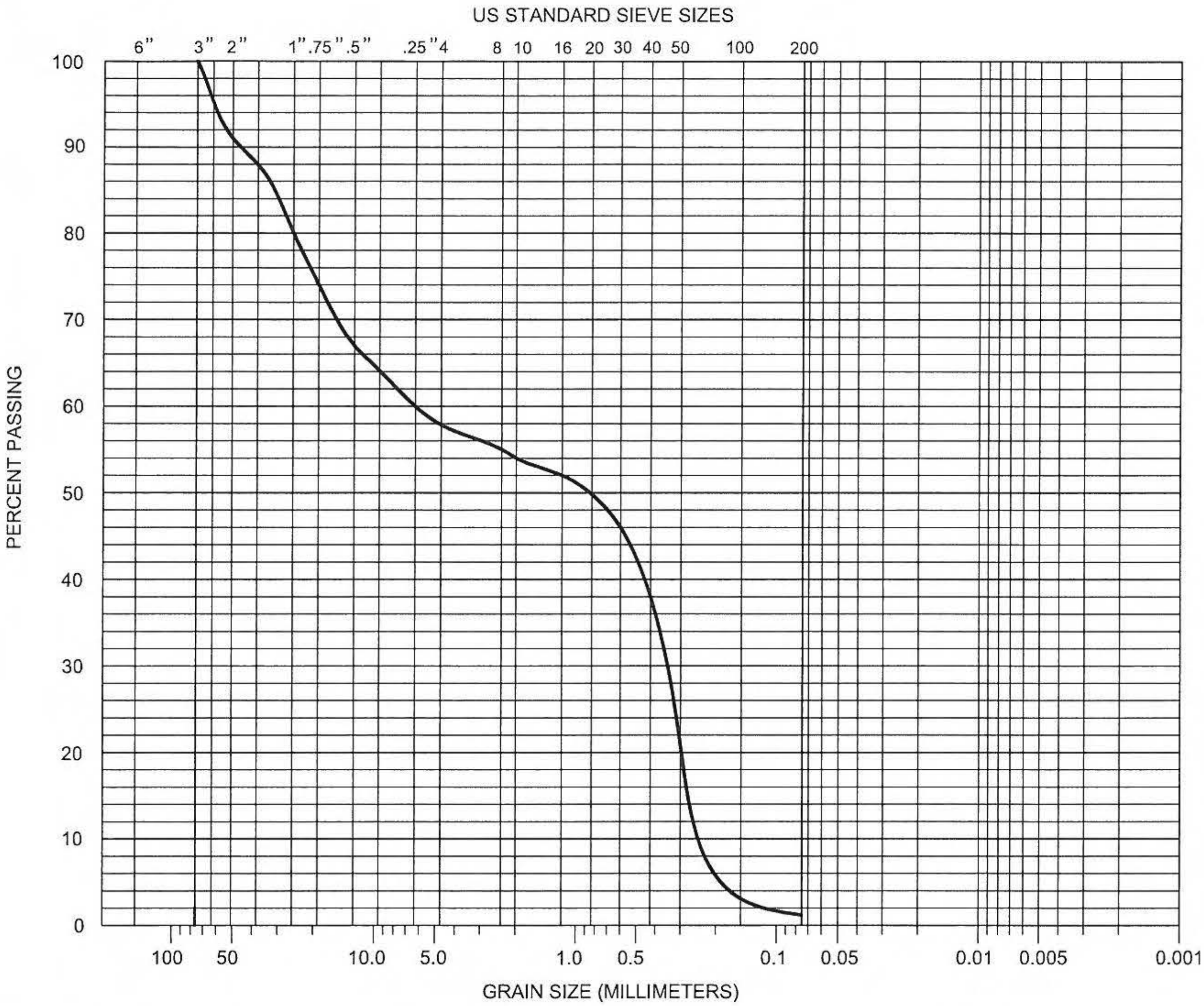
COBBLES	GRAVEL		SAND			SILT AND CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	

SYMBOL	SAMPLE LOCATION	FIELD MOISTURE (%)	% PASSING NO. 200 SIEVE	% PASSING 2 μ	UNIFIED SOIL CLASSIFICATION
———	G2A 2010 @ 0 - 4 INCHES	--	1.4	--	--

GRADATION TEST RESULTS – ASTM D422

PROJECT NO. 2139.1.1	CH2M HILL KINDER MORGAN LINNTON TERMINAL LABORATORY TESTING	LAB NO. 10-339

Northwest Testing, Inc.
A Division of Northwest Geotech, Inc.



COBBLES	GRAVEL		SAND			SILT AND CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	

SYMBOL	SAMPLE LOCATION	FIELD MOISTURE (%)	% PASSING NO. 200 SIEVE	% PASSING 2 μ	UNIFIED SOIL CLASSIFICATION
——	G1B 2010	--	1.1	--	--

GRADATION TEST RESULTS – ASTM D422

PROJECT NO. 2139.1.1	CH2M HILL KINDER MORGAN LINNTON TERMINAL LABORATORY TESTING	LAB NO. 10-339

Northwest Testing, Inc.
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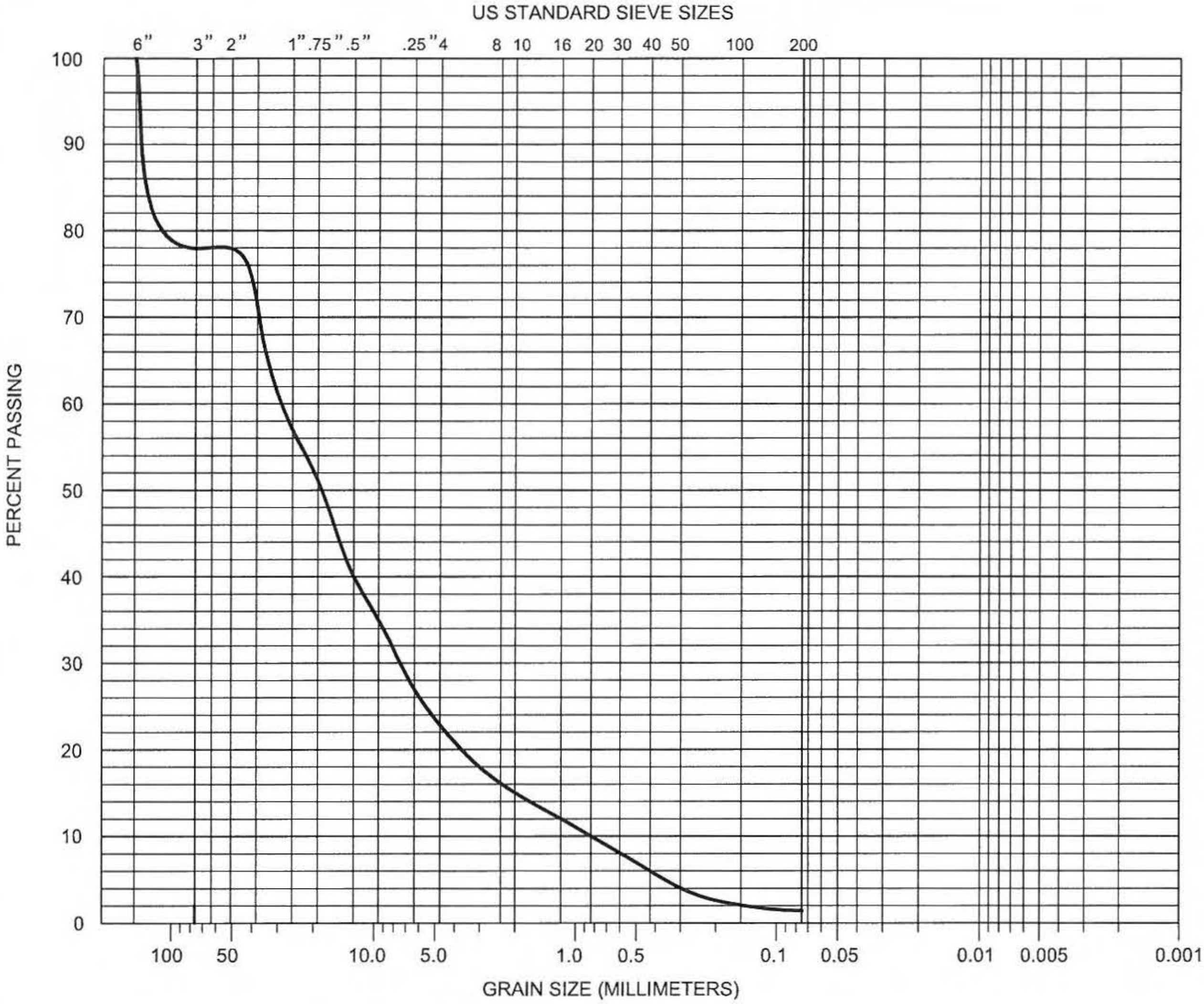


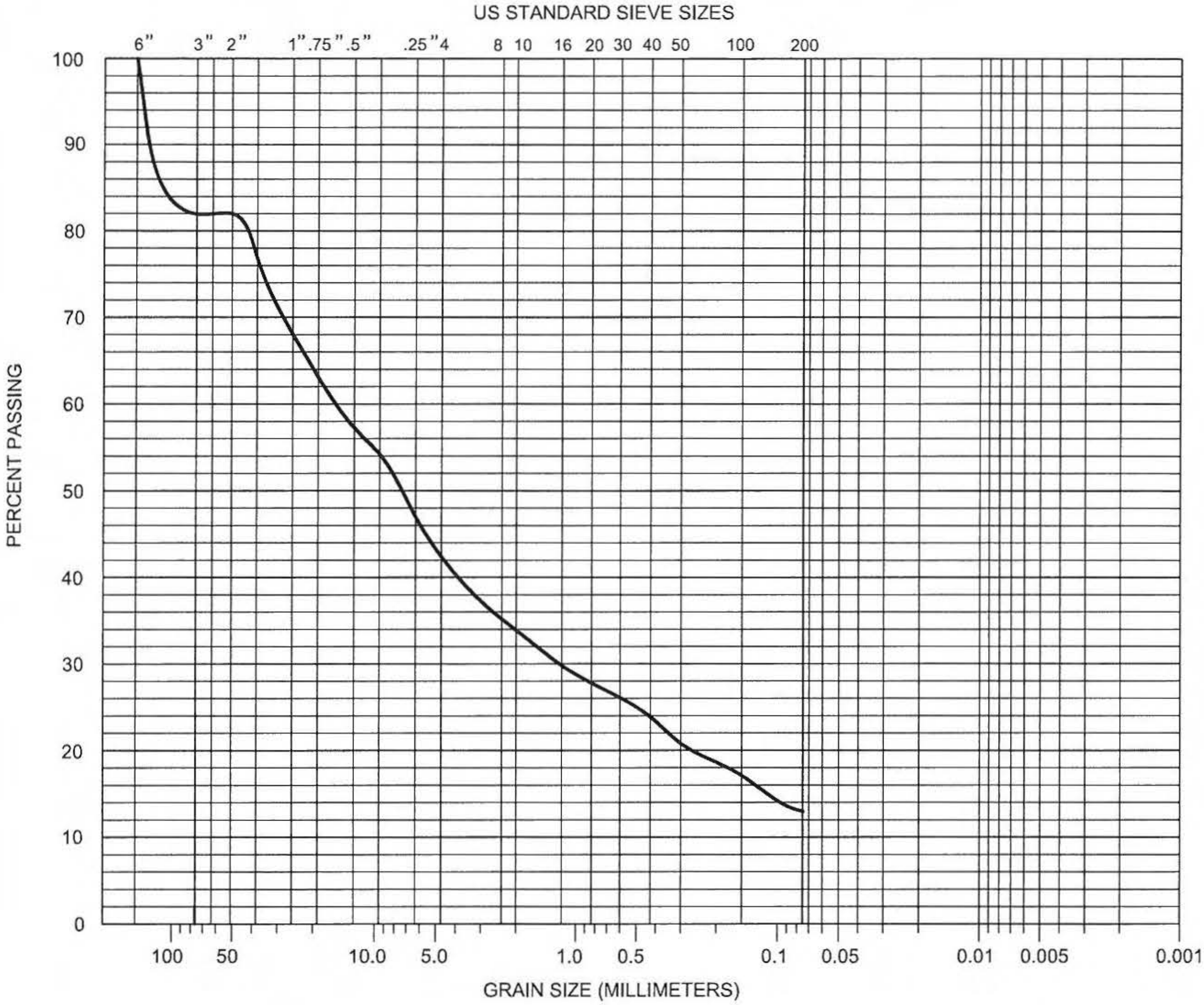
COBBLES	GRAVEL		SAND			SILT AND CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	

SYMBOL	SAMPLE LOCATION	FIELD MOISTURE (%)	% PASSING NO. 200 SIEVE	% PASSING 2 μ	UNIFIED SOIL CLASSIFICATION
———	G2B 2010 @ 4 - 8 INCHES	--	1.4	--	--

GRADATION TEST RESULTS – ASTM D422

PROJECT NO. 2139.1.1	CH2M HILL KINDER MORGAN LINNTON TERMINAL LABORATORY TESTING	LAB NO. 10-339

Northwest Testing, Inc.
A Division of Northwest Geotech, Inc.



COBBLES	GRAVEL		SAND			SILT AND CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	

SYMBOL	SAMPLE LOCATION	FIELD MOISTURE (%)	% PASSING NO. 200 SIEVE	% PASSING 2 μ	UNIFIED SOIL CLASSIFICATION
———	G3A 2010	--	13.1	--	--

GRADATION TEST RESULTS – ASTM D422

PROJECT NO. 2139.1.1	CH2M HILL KINDER MORGAN LINNTON TERMINAL LABORATORY TESTING	LAB NO. 10-339

Northwest Testing, Inc.
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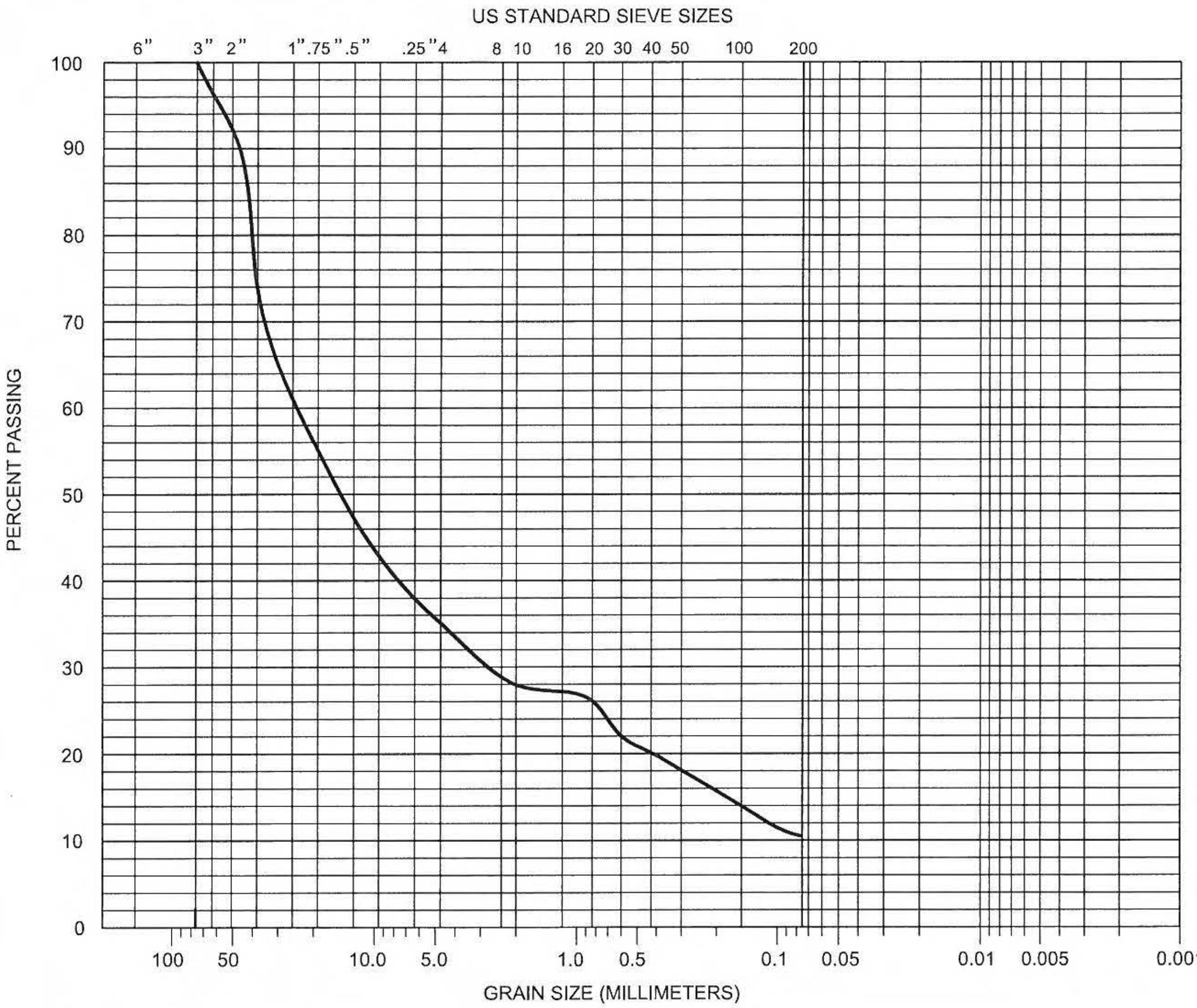


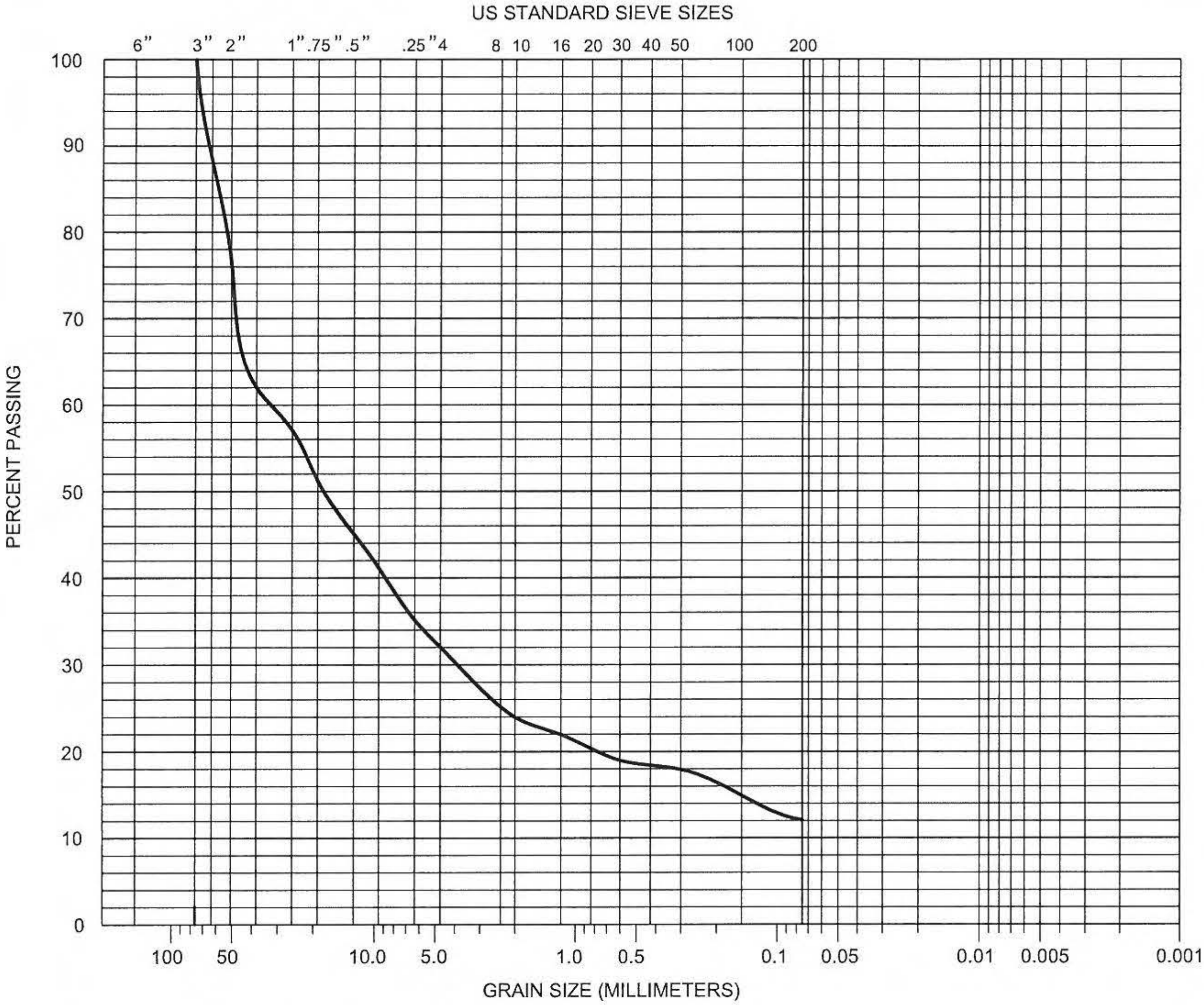
COBBLES	GRAVEL		SAND			SILT AND CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	

SYMBOL	SAMPLE LOCATION	FIELD MOISTURE (%)	% PASSING NO. 200 SIEVE	% PASSING 2 μ	UNIFIED SOIL CLASSIFICATION
———	G3B 2010	--	10.6	--	--

GRADATION TEST RESULTS – ASTM D422

PROJECT NO. 2139.1.1	CH2M HILL KINDER MORGAN LINNTON TERMINAL LABORATORY TESTING	LAB NO. 10-339

Northwest Testing, Inc.
A Division of Northwest Geotech, Inc.



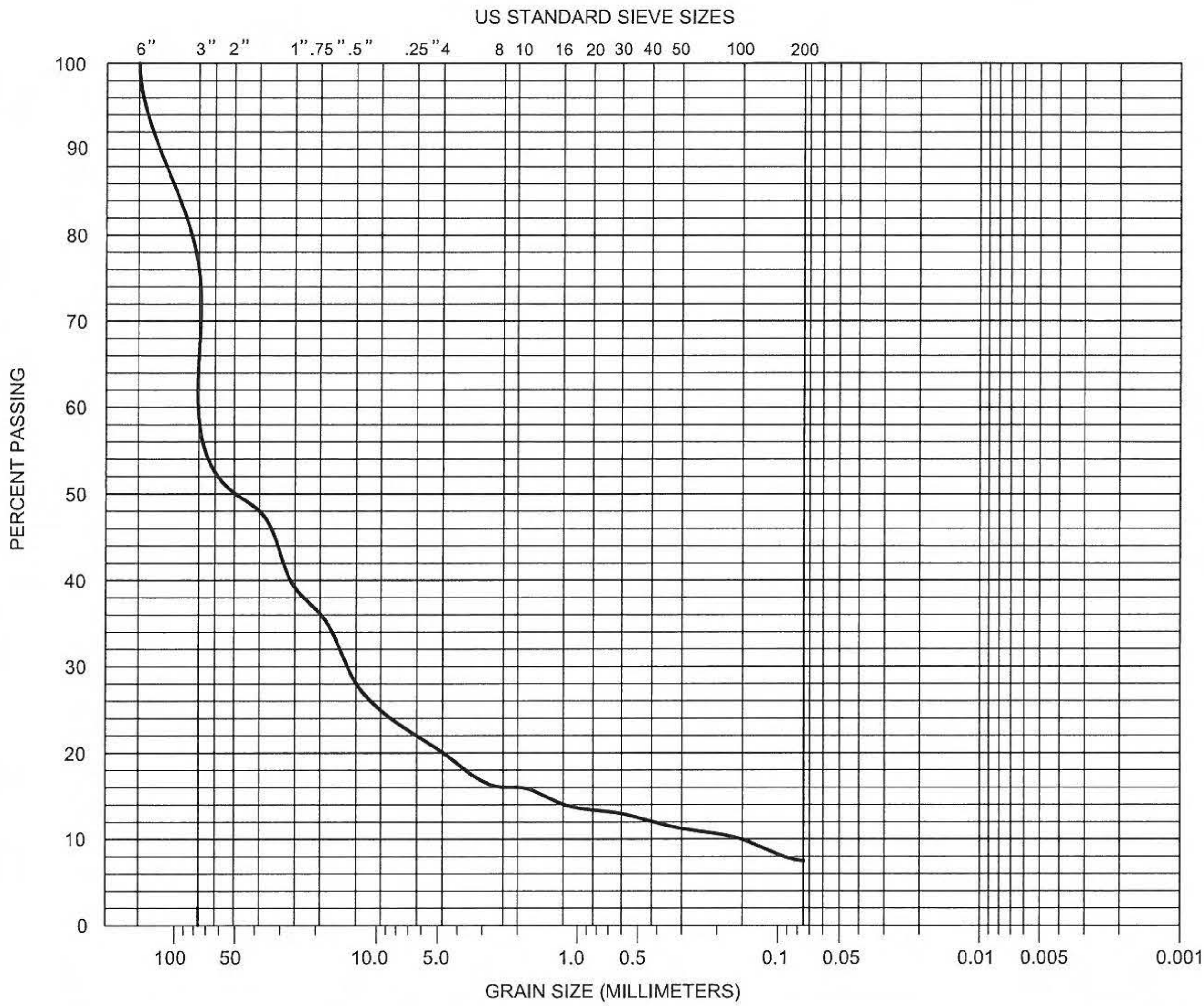
COBBLES	GRAVEL		SAND			SILT AND CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	

SYMBOL	SAMPLE LOCATION	FIELD MOISTURE (%)	% PASSING NO. 200 SIEVE	% PASSING 2 μ	UNIFIED SOIL CLASSIFICATION
——	G4A 2010	--	12.1	--	--

GRADATION TEST RESULTS – ASTM D422

PROJECT NO. 2139.1.1	CH2M HILL KINDER MORGAN LINNTON TERMINAL LABORATORY TESTING	LAB NO. 10-339

Northwest Testing, Inc.
A Division of Northwest Geotech, Inc.



COBBLES	GRAVEL		SAND			SILT AND CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	

SYMBOL	SAMPLE LOCATION	FIELD MOISTURE (%)	% PASSING NO. 200 SIEVE	% PASSING 2 μ	UNIFIED SOIL CLASSIFICATION
———	G4B 2010	--	7.4	--	--

GRADATION TEST RESULTS – ASTM D422

PROJECT NO. 2139.1.1	CH2M HILL KINDER MORGAN LINNTON TERMINAL LABORATORY TESTING	LAB NO. 10-339

Northwest Testing, Inc.
A Division of Northwest Geotech, Inc.

APPENDIX D

Wind Speed and Direction

Wind Speed and Direction

Wind velocities and frequency of wind direction data were obtained from the NOAA, National Weather Service Forecast Office for the Portland International Airport for the period between 1948 and 1995. Values for the hours of 7 AM, 1 PM, and 7 PM are provided in the data set. Table 3 shows the available data for the frequency of wind direction and Table 4 provides the available data for average wind speed based on direction and time of day in miles per hour. Directions are provided for each 22.5 degrees of wind direction where 0 and 360 degrees are true north, 22.5 degrees is NNE, 45 degrees is NE, etc. The direction provided for wind direction is the direction the wind is blowing from.

The Site is located on the west bank of the Willamette River where the river bank is aligned in the north by northwest (NNW) to south by southeast (SSE) direction. Wind blowing over land will not result in waves that strike the river bank of the site. Accordingly, wind blowing from the south (S), south by southwest (SSW), southwest (SW), west of south (WS), west (W) west of north (WN), and northwest (NW) will have very little impact on wind generated waves at the site. The most direct waves to strike the river bank at the site will be those generated from wind blowing from the north by northeast (NNE) and east by southeast (ESE).

According to the National Weather Service Forecast Office at Portland, Oregon, the majority of the destructive surface winds in Oregon are from the southwest. Under certain conditions, very strong east winds may occur, but these are usually limited to small areas in the vicinity of the Columbia River Gorge or other low mountain passes (NOAA, 2010).

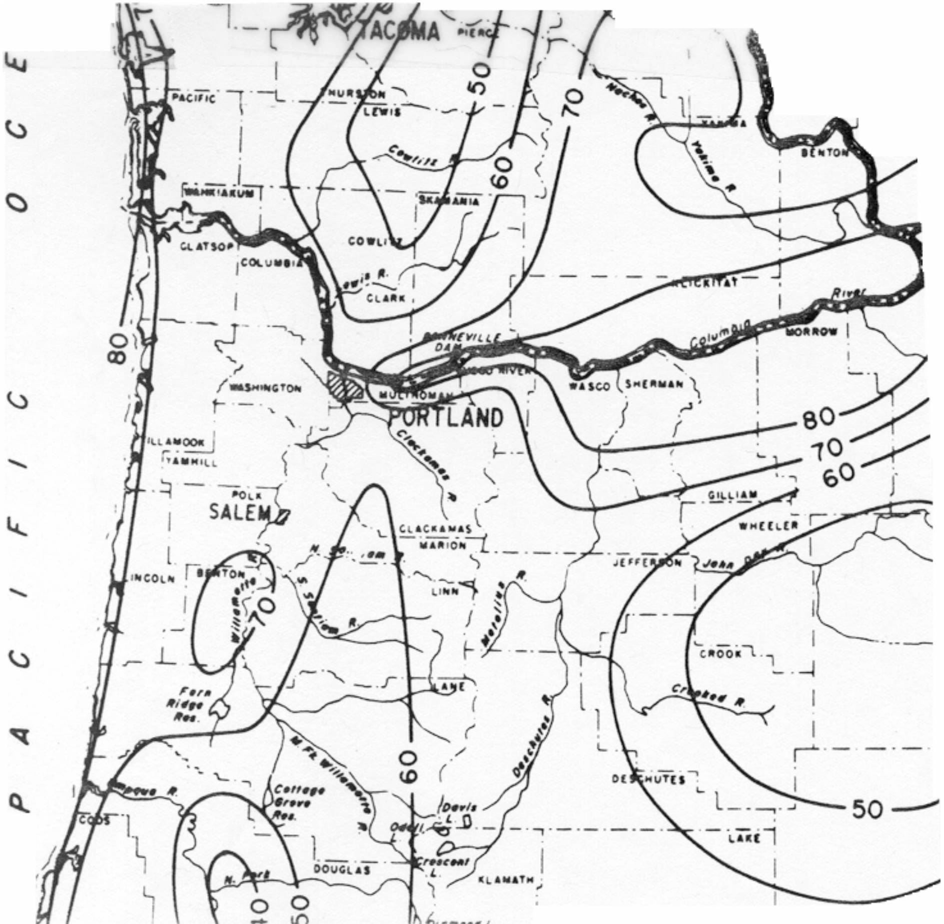
Data in Table D-1 indicates that wind is either calm or blows from between the S and NW approximately 54 percent of the time over the entire year and about 48 percent of the time during the winter months between November and March when flood events on the Willamette River are most common. This means that the river bank at the site will not be impacted by about 50 percent of the waves that result from wind. The data in Table D-2 indicates that, of the wind directions that will produce waves that strike the river bank at the site, the greatest average wind velocities during winter months come out of the east (E) and east of southeast (ESE) and blow at average speeds of about 12.2 and 11.9 mph, respectively.

The longest fetch lengths, the lengths of open water over which wind blows to create wind-generated waves, are approximately 2.3 miles for wind blowing from the north (N) and from the south by southeast (SSE). As expected these directions are for wind blowing up and down river. Wind blows from the north and south by southeast during the winter months only about 1.8 and 3.8 percent of the time, respectively.

The fetch length for waves that will more directly strike the river bank at the site are on the order of 0.3 to 0.6 miles, which includes a fetch length of about 0.6 miles for wind blowing from the East.

A regional overview of wind hazards in western Oregon was developed for the Bonneville Power Administration Service Area (Wantz and Sinclair, 1981). This document provides a regional map for sustained wind speeds in western Oregon for the 2-year and 50-year return period. Because the likelihood of having a major flood event combined with a major wind storm is extremely remote, it is viewed as overly conservative to evaluate erosion potential due to wind-generated waves from a 50-year wind event for this study. The potential for a 2-year return period wind event occurring during a time of high river water is not out of the question. The wind speed contour map for the 2-year recurrence interval for western Oregon in kilometers per hour (km/h) (Wantz and Sinclair, 1981) is provided in Figure D-1. This figure shows that the sustained wind speed for the 2-year wind event is between 60 and 70 km/h (37 to 43 mph).

Figure 7.1
Wind Speed Contours for 2-Year Recurrence Interval
(km/hour)



Source: *Distribution of Extreme Wind Speeds in the Bonneville Power Administration Service Area, Journal of Applied Meteorology, Vol. 20, pp 1400 - 1411. 1981 (Wantz and Sinclair)*

FIGURE D-1

Table D-1
Frequency of Wind Direction Based on Time of Day, Portland International Airport
Data Based on Hourly Observations Between 1948 and 1995

LST		Calm	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WS	W	WN	NW	NNW
	7	12.4	1.3	0.6	1.4	2.5	7.8	23.4	12.6	4.3	8	8.2	3.8	2.1	2.7	3.4	2.9	2.2
	13	4.8	1.9	0.8	1.4	1.9	9.3	22.9	12.2	3.5	7.1	10.7	5.4	3.3	3.8	5.4	3.8	2.1
Jan	***19***	9.1	0.8	0.4	0.8	2	8.3	31.4	14.5	3.4	7.5	7.9	4.3	1.9	2.3	2.3	1.9	1.2
	7	16.4	1.1	1.1	1	1.9	5.7	22	11.6	4.6	8.6	9.2	4.1	2	3.2	3.7	3.1	1.3
	13	4.1	2.3	1	1.7	2.9	7.8	18.1	11.1	2.8	7.2	11.4	5.6	3.4	5.3	6.5	5.6	3.1
Feb	***19***	10.2	1.8	0.6	0.8	1.6	7.1	25.6	14.2	3.9	7.8	7.7	3.3	2.8	3.2	4.6	3	2
	7	19.4	1.3	0.3	0.7	1.3	4.7	17.8	8.5	3.9	10.2	11.1	4.1	3.2	4.3	4.3	3.4	2.2
	13	2.9	4.3	2.3	1.6	4.5	6.7	9.1	4.7	1.7	9	11.3	7.3	5.6	5.8	10.6	6.8	5.2
Mar	***19***	8.5	3.2	1.2	1	2.8	6.5	15	7.1	4.2	7.4	7.5	3.8	4.7	5.3	7.5	8.1	5.8
	7	18.9	2	0.6	1	1.3	3.1	13	6.8	4.8	10.1	10.1	3.3	2.8	4.9	7.4	7	3
	13	3.3	5.8	2.9	3.6	2.8	5.2	5	2.4	1.8	7.7	10	7.4	7.3	6.3	12.5	8.8	7
Apr	***19***	6	5.1	1	1.4	3.2	5.7	6.7	3.5	2.1	5.9	5.1	4.5	4.9	5.8	10.4	16.2	12.1
	7	16.5	4.2	1.5	1	1.6	4.1	5.7	4.5	4.3	8.9	8.5	4.5	2.8	3.8	8.8	11.9	7.8
	13	2	6.5	3.3	3.4	3.2	4.5	2.5	2.1	1.9	5.3	6.6	5.8	5.8	6.8	16.1	15.6	9.1
May	***19***	3.7	8	1.9	1.4	2.1	3.5	4.7	1.5	1.5	3.4	2.5	3.2	3.7	5.5	10.6	21.7	21.3
	7	16.4	9.2	2.1	2.3	2.1	2.7	4.5	3	3.6	7.8	7.3	3.8	1.8	2.7	5.2	12.2	12.6
	13	1.8	7.3	3.9	3.1	3	2.3	1.7	1	1.4	4.6	6	3.8	5.1	7.7	17.2	18.8	11.8
Jun	***19***	3.2	9.9	1.3	0.6	1	2.4	2.3	0.8	1.1	2.8	2.8	2.1	2.7	4.9	10.8	25.5	25.5
	7	10.6	12.9	4.2	2.5	2.1	2	3.2	2.1	3	4.5	3.2	1.6	2.1	3.1	8	16.1	18.7
	13	1.7	7.9	3.6	2.5	2.5	1.8	0.9	0.5	0.8	2.5	2.3	2.3	3.4	7.6	22.5	22.5	15.5
Jul	***19***	1.2	9.9	1.3	0.5	0.8	1.4	1	0.8	0.4	1.4	0.9	1	1.9	2.9	7.5	31.3	36.6
	7	15	9.6	3.8	2.4	1.2	2.6	4.4	5.4	4.4	5.9	3.8	2.5	1.9	3.2	6.3	13.9	13.9
	13	1.5	7.5	2.9	2.7	2.3	2.2	1	0.8	1.2	3.2	3.1	2.3	2.9	7.7	23.4	23.4	12
Aug	***19***	1.6	8.5	1.1	0.9	1.4	1.4	1.8	1.2	0.6	1.5	1.4	1.4	1.2	3.6	8.2	29.6	34.5
	7	18.8	4.4	2.4	1.1	0.9	2.1	8.2	8	5.7	7	5.2	4.5	3.1	6.5	8.4	8	5.8
	13	2.6	7.1	3.4	2.6	3	6.7	3.7	1.9	1.9	4	5.3	4	4.5	7.2	16.6	15.7	9.7
Sep	***19***	6.5	5.2	1.6	1.3	2	5.5	6.8	2.7	1.6	3.1	2.3	2.1	3.1	5.7	11.6	21.1	18
	7	19.8	2.7	1.9	1.2	1.2	2.5	12.5	10.5	5.4	8.7	6.1	4	4.2	4.9	6.5	5.4	2.6
	13	5.6	4.3	2.3	2.2	2.2	6.2	9.3	4.7	2.1	8.6	7.8	4.7	4.1	6.7	11	11.2	6.7
Oct	***19***	14.8	2	0.3	1	2.1	5.8	13.9	9	3.8	4.7	4.8	3.2	3.9	6	9.8	9.4	5.3
	7	13.2	1.5	0.9	1.3	1.4	3.8	18.2	13.3	6	9.6	8.4	4.2	3.5	4.8	4.9	3.8	1.3
	13	5.7	1.9	1.2	1	2.1	6	17.7	10.4	2.9	10.8	9.9	5.5	3	5.1	7.7	5.6	3.6
Nov	***19***	12.2	1	0.6	0.6	0.9	5.7	24.8	14	4.9	8	8.3	4	2.7	3.7	3.1	4	1.7
	6	12.7	1.6	1	0.9	1.5	6	23.6	13.9	4.8	8.9	7.8	4.7	2.7	3.6	3.3	1.8	1.6
	13	5.1	2.1	1.1	1.2	2.2	6.7	22.2	12.6	2.9	7.4	11.2	5.1	3.6	3.2	5.6	5	2.9
Dec	***19***	9.5	0.8	0.9	0.8	1.2	7	28.5	16.3	3.6	6.9	8.8	3.6	2.5	2.8	2.7	2.8	1.8
Average	**Full Year**	8.83	4.64	1.70	1.53	2.02	4.80	12.03	6.95	3.08	6.56	6.79	3.91	3.34	4.79	8.73	11.30	9.10
	Winter Months (Nov – March)	9.75	1.79	0.93	1.08	2.05	6.61	21.35	11.80	3.83	8.29	9.29	4.59	3.13	3.94	5.04	4.11	2.53

Table D-2
Average Wind Speed (miles per hour) Based on Direction and Time of Day, Portland International Airport
Data Based on Hourly Observations Between 1948 and 1995

LST hour		N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
	7	4.8	5.8	5.6	9.0	13.1	11.7	10.4	8.9	10.8	14.3	10.7	6.0	4.3	6.4	6.1	6.1
	13	4.1	5.9	5.3	14.1	13.9	13.3	11.7	9.0	13.5	15.2	13.1	11.2	7.0	6.9	6.6	6.3
Jan	***19***	4.5	4.9	5.2	11.0	12.7	11.6	10.5	10.1	11.5	14.4	11.6	8.4	5.3	6.0	6.4	6.7
	7	4.5	4.1	4.4	7.0	10.9	10.9	9.7	8.5	10.1	14.4	11.4	7.2	5.3	6.0	5.6	4.5
	13	5.1	5.8	6.9	8.5	13.1	13.7	12.0	10.8	12.4	15.5	13.8	10.4	7.5	7.2	7.7	5.5
Feb	***19***	4.4	5.8	5.6	9.8	12.1	11.8	10.4	8.2	10.9	13.6	11.8	9.5	6.4	7.1	8.4	7.6
	7	4.1	4.8	4.4	5.9	7.9	9.5	8.3	7.4	10.0	12.1	9.4	6.1	5.2	5.6	6.8	6.1
	13	5.5	5.3	6.2	8.1	12.0	12.1	12.8	12.4	12.5	15.1	12.9	11.4	8.9	8.9	8.4	7.0
Mar	***19***	7.2	5.2	6.8	6.7	9.3	10.0	9.5	8.9	10.5	12.3	12.2	8.9	7.5	8.1	8.7	7.7
	7	4.6	5.1	4.0	5.1	6.6	7.9	6.9	6.7	9.2	10.5	9.4	6.7	5.4	6.0	6.3	6.2
	13	5.5	5.9	5.8	8.1	11.0	10.9	9.2	9.8	12.3	13.2	11.8	9.5	9.1	9.1	8.4	8.1
Apr	***19***	7.6	5.9	5.2	6.4	8.1	8.7	8.4	8.5	10.0	11.2	10.0	9.8	7.6	8.1	10.0	10.0
	7	4.5	4.7	4.4	4.7	5.3	7.6	6.7	7.2	7.8	9.2	8.5	6.4	5.1	5.9	6.4	6.3
	13	6.1	5.8	5.6	7.7	8.9	9.4	7.5	8.9	10.6	11.0	10.5	8.9	8.3	8.9	8.3	7.8
May	***19***	9.1	6.4	6.8	7.8	6.8	7.8	8.2	8.4	8.6	10.9	9.0	8.9	8.6	9.2	10.7	10.6
	7	5.5	5.3	4.8	4.8	4.4	6.1	6.8	6.4	7.5	9.3	8.7	5.8	4.6	5.6	6.9	6.9
	13	6.9	5.9	6.0	7.4	7.2	7.6	7.7	7.0	9.4	10.9	10.6	8.9	8.4	8.7	8.5	8.2
Jun	***19***	10.4	7.5	5.8	6.7	5.6	7.5	8.4	9.0	8.5	9.7	9.0	10.4	8.2	9.1	10.9	11.3
	7	6.1	5.1	4.9	4.6	4.7	6.7	7.2	7.2	6.8	7.8	7.5	4.9	4.8	5.8	6.3	6.7
	13	6.8	6.1	6.1	7.8	8.6	8.6	6.2	8.2	9.9	10.7	9.5	8.4	8.2	9.3	8.9	8.5
Jul	***19***	10.2	6.8	6.6	7.7	6.4	7.2	7.9	7.1	8.4	12.5	10.4	8.4	7.5	10.0	11.7	11.8
	7	5.3	5.1	4.9	4.5	4.1	6.3	6.2	6.2	6.7	7.8	6.4	4.8	4.7	5.5	6.3	6.4
	13	6.7	6.0	6.2	7.9	9.2	8.5	6.3	8.6	9.2	10.7	10.2	8.9	7.8	8.9	8.6	7.5
Aug	***19***	9.2	8.4	5.8	6.8	5.6	8.9	7.4	9.4	6.9	9.3	9.5	9.2	7.1	9.0	10.9	11.0
	7	5.2	4.8	5.5	6.0	5.9	6.4	5.8	6.1	6.3	8.1	5.8	4.7	4.8	6.0	6.6	6.0
	13	6.3	6.1	7.5	12.0	13.3	10.1	7.6	7.6	11.2	11.0	10.6	7.8	7.8	8.7	7.8	7.5
Sep	***19***	8.9	7.7	7.1	7.7	7.8	7.6	7.8	5.9	8.1	11.4	9.7	7.7	5.9	7.7	8.9	9.9
	7	4.9	5.2	4.8	5.1	7.1	8.5	7.2	6.0	8.1	9.7	7.1	4.6	4.6	5.4	5.9	6.9
	13	5.3	5.6	6.0	9.4	12.4	12.1	10.4	9.1	11.0	12.2	10.1	8.2	6.4	7.6	7.0	6.8
Oct	***19***	5.9	5.5	5.1	6.6	7.9	8.5	7.5	8.2	8.6	10.8	9.0	5.5	5.4	6.8	7.6	8.6
	7	4.6	5.4	4.9	6.9	12.1	11.2	9.1	7.0	10.2	12.3	8.2	6.2	5.6	6.1	6.8	7.4
	13	5.4	5.3	6.3	7.8	13.8	13.0	11.4	9.7	12.0	13.8	13.2	10.6	7.6	7.7	7.5	5.4
Nov	***19***	5.2	4.9	5.6	9.9	11.8	11.4	9.3	9.0	10.9	12.8	9.4	7.6	5.5	6.7	6.0	7.0
	7	4.1	5.5	6.3	7.0	12.5	12.4	10.4	6.9	10.2	14.0	11.0	7.4	5.2	6.0	7.0	6.3
	13	5.2	4.4	6.0	9.2	14.6	13.3	11.5	9.2	12.4	14.6	12.8	9.0	7.5	6.7	7.0	6.7
Dec	***19***	5.2	4.8	7.1	10.2	12.9	12.2	10.6	7.9	11.8	14.0	10.4	7.1	5.6	6.4	6.4	5.4
Average	**Full Year**	6.0	5.6	5.7	7.7	9.4	9.8	8.7	8.2	9.9	11.8	10.1	7.9	6.5	7.3	7.7	7.5
	Winter Months (Nov - March)	4.9	5.2	5.8	8.7	12.2	11.9	10.5	8.9	11.3	13.9	11.5	8.5	6.3	6.8	7.0	6.4